U.S. Army Center for Health Promotion and Preventive Medicine

USACHPPM

CONSERVARE SALUTEM

Health Risk Assessment
Draft Report
Open Burning of Propellant Bags
Massachusetts Military Reservation, MA
Project No. 30-EJ-6995-97

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Submitted by:

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Readiness Thru Health

U.S. Army Center for Health Promotion and Preventive Medicine

The lineage of the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) can be traced back over 50 years. This organization began as the U.S. Army Industrial Hygiene Laboratory, established during the industrial buildup for World War II, under the direct supervision of the Army Surgeon General. Its original location was at the Johns Hopkins School of Hygiene and Public Health. Its mission was to conduct occupational health surveys and investigations within the Department of Defense's (DOD's) industrial production base. It was staffed with three personnel and had a limited annual operating budget of three thousand dollars.

Most recently, it became internationally known as the U.S. Army Environmental Hygiene Agency (AEHA). Its mission expanded to support worldwide preventive medicine programs of the Army, DOD, and other Federal agencies as directed by the Army Medical Command or the Office of The Surgeon General, through consultations, support services, investigations, on-site visits, and training.

On 1 August 1994, AEHA was redesignated the U.S. Army Center for Health Promotion and Preventive Medicine with a provisional status and a commanding general officer. On 1 October 1995, the nonprovisional status was approved with a mission of providing preventive medicine and health promotion leadership, direction, and services for America's Army.

The organization's quest has always been one of excellence and the provision of quality service. Today, its goal is to be an established world-class center of excellence for achieving and maintaining a fit, healthy, and ready force. To achieve that end, the CHPPM holds firmly to its values which are steeped in rich military heritage:

★ *Integrity is the foundation*
★ *Excellence is the standard*
★ *Customer satisfaction is the focus*
★ *Its people are the most valued resource*
★ *Continuous quality improvement is the pathway*

This organization stands on the threshold of even greater challenges and responsibilities. It has been reorganized and reengineered to support the Army of the future. The CHPPM now has three direct support activities located in Fort Meade, Maryland; Fort McPherson, Georgia; and Fitzsimons Army Medical Center, Aurora, Colorado; to provide responsive regional health promotion and preventive medicine support across the U.S. There are also two CHPPM overseas commands in Landstuhl, Germany and Camp Zama, Japan who contribute to the success of CHPPM's increasing global mission. As CHPPM moves into the 21st Century, new programs relating to fitness, health promotion, wellness, and disease surveillance are being added. As always, CHPPM stands firm in its commitment to Army readiness. It is an organization proud of its fine history, yet equally excited about its challenging future.

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Acronyms and Abbreviations

ATSDR	Agency of Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
$CaCO_3$	calcium carbonate
CARB	California Air Resources Board
C/DR	concentration and deposition rates
cm	centimeter
COC	chemicals of concern
CRS	Congressional Research Service
CSF	cancer slope factor
CSM	conceptual site model
DNT	dinitrotoluene
DPA	diphenylamine
DPG	Dugway Proving Grounds
ECAO	Environmental Criteria and Assessment Office
°F	temperature in degrees Fahrenheit
HCB	hexachlorobenzene
HCl	hydrogen chloride
HEAST	health effects assessment summary tables
Hg	mercury
HI	hazard index
HQ	hazard quotient
HQ_{inh}	inhalation hazard quotient for substance, unitless
hr	hour
HHRA	human health risk assessment
IED	indirect exposure document
IEDA	indirect exposure document addendum
IG	Implementation Guidance
IRIS	integrated risk information system
ISCST3	Industrial Source Complex - Short Term, Version 3, Model
K_{ow}	octanol/water partition coefficient
kg	kilogram
km	kilometer
L	liter
LOAEL	lowest observed adverse effect level
MAARNG	Massachusetts Army National Guard
MADEP	Massachusetts Department of Environmental Protection
MADPH	Massachusetts Department of Public Health
mg	milligram
MMR	Massachusetts Military Reservation
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Science
NAWQC	National Ambient Water Quality Criteria

NOEL	no observed effect level
NOAEL	no observed adverse effect level
NRC	National Research Council
OANGB	Otis Air National Guard Bases
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
P_C	particulate air concentration
P_{DD}	particulate dry deposition
P_{WD}	particulate wet deposition
PAVE-PAWS	Precision Acquisition Vehicle Entry Phased Array Warning System
PCBs	polychlorinated biphenyls
PICs	products of incomplete combustion
PM	particulate matter
$PM_{2.5}$	particulates equal to or less than 2.5 um
PM_{10}	particulates equal to or less than 10 μm
POHCs	products of hazardous combustion
RA	risk assessment
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration, mg/m^3
RfD	reference dose (mg/kg/day)
SVOC	semi-volatile organic compounds
TIC	tentatively identified compounds
TRV	Toxicity Reference Value
TSC	USEPA Superfund Health Risk Technical Support Center
UR	unit risk
USACE	U.S. Army Corps of Engineers
USAEHA	U.S. Army Environmental Hygiene Agency
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
V_C	vapor air concentration
V_{WD}	vapor wet deposition
VOC	volatile organic compound
WQB	water quality benchmark
yr	year

EXECUTIVE SUMMARY

Purpose:

The purpose of this human health risk assessment (HHRA) was to determine if the open burning of propellant bags at MMR caused any adverse health effects to people living on Cape Cod.

Methods:

An HHRA looks at the ways a person can be exposed to (come into contact with) a substance, and whether or not that contact can cause an adverse health effect. You may be exposed to a substance by eating, drinking, breathing, or getting the chemical on your skin. There are many factors that decide if a person will have an adverse health effect if they are exposed to a substance. They include how long the person was in contact with the substance, how much of the substance they were exposed to, how much they weigh, their age, and their lifestyle. A person may come into contact with a substance and not have any adverse health effects.

In this HHRA the possibility of exposure to the substances put into the air when the propellant bags were burned was investigated. The types of exposure considered were: breathing, swallowing soil, eating vegetables from a home garden, eating fish caught in local ponds, and swallowing water while swimming. In this HHRA the exposures for both people who live on and off MMR, and for people who work or go to school on MMR or off MMR were included.

Results:

In a HHRA there are two types of results. The first result is the risk of developing cancer. This is a number that is the extra chance of getting cancer. In this study the highest extra risk of getting cancer from being exposed to the substances from propellant bag burning was very small. The chances of getting cancer from propellant bag burning were very small. Nearly 2500 times as much propellant would need to be burned to reach the level that USEPA considers a concern.

The second result is the hazard quotient. The amount of the substance that a person is exposed to is compared to an amount that studies show is not likely to cause a health effect. This number is the hazard quotient. The numbers for all substances are added to get the hazard index. If the hazard index is less than 1.0, there is not enough of the substance in the environment to cause a health effect. The highest hazard index was 0.0002. This means that the amount of chemicals from propellant bag burning that people who live on or near MMR were exposed to was much less than the amount needed to cause an adverse health effect.

This HHRA also found that the amount of lead in the soil and air, and the amounts of particulates in the air, from propellant bag burning are well within the limits that USEPA considers safe.

Conclusion:

In this HHRA we found that it is very unlikely that the propellant bag burning at MMR caused any adverse health effects.

Section 1

INTRODUCTION

1.0 Introduction

1.1 Project Scope and Objective:

This document outlines the procedures that were followed while conducting a multi-pathway human health risk assessment (HHRA) to evaluate direct and indirect cancer risks, and chronic noncancer hazards associated with the past practice of open burning of propellant bags during training at the Camp Edwards portion of the Massachusetts Military Reservation (MMR).

Camp Edwards is used by the Massachusetts Army National Guard (MAARNG) and the United States Army Reserve for training purposes. Historically, this training extends back prior to 1941. This training previously included the firing of mortars and artillery. Until 1992, unused mortar and artillery propellant was disposed of via open burning at gun points during each training exercise (ATSDR, 1994).

In January 1992, a Boston University study investigated an increased incidence of cancer in the upper Cape Cod region. Several potential sources of environmental contamination, including the Canal Electric Plant, Barnstable Airport, and propellant bag burning at MMR, were identified (Boston University School of Public Health, 1991). Based on recommendations from the Agency of Toxic Substances and Disease Registry (ATSDR), the MAANG voluntarily stopped burning artillery propellants (MADEP, 1994). The burning of mortar propellants continued until 1997 when all firing exercises at MMR were ceased.

In 1992, the MAARNG agreed to conduct an air monitoring study at MMR. Because of public concern over the potential health effects of a test burn, the MAANG agreed to allow the test burn to be conducted in a facility away from Camp Edwards. The test burn was conducted at Dugway Proving Ground (DPG) in a Bang Box test facility. The Bang Box test facility was specifically designed for open burning and open detonation emissions testing. Data from the test burning was used to develop chemical emission rates from the burning of artillery and mortar propellants. These emission rates were used in this HHRA as described in Section 2.0.

This HHRA was conducted in response to Recommendation Number Seven contained in the ATSDR Public Health Assessment for Otis Air National Guard Base/Camp Edwards dated January 25, 1994 (ATSDR, 1994). The recommendation read, "Refrain from the practice of propellant bag burning until a test burn is conducted with concurrent air monitoring at a location and in a manner that would not place residents at public health risk." This HHRA addressed that recommendation by incorporating the results of the Bang Box test into an HHRA to assess the potential health effects from the burning of excess propellant bags.

The purpose of this HHRA is to determine any Excess Lifetime Cancer Risk (ELCR) and any chronic noncancer health effects that may have been created by

propellant bag burning at MMR. This document describes the methodology that was followed, along with the results of the HHRA.

1.2 Human Health Risk Assessment Methodology

A health risk assessment is the use of a factual base to define the health effects of exposure of individuals or populations to hazardous substances. In a health risk assessment, the goal is to determine what the health risk is from a specific site. Unlike epidemiological studies, where the goal is to determine if an exposure is associated with a health effect, a health risk assessment assumes a cause and effect relationship if the exposure pathways are present and the exposure exceeds a certain level. In the HHRA, the risk assessor determines if there is a likely exposure to the chemical, and if it is in amounts sufficient to cause harm. The health risk is then calculated for the individuals defined in the exposure scenarios.

This risk assessment followed the fundamental paradigm adapted by the United States Environmental Protection Agency (USEPA) from well-established chemical risk assessment principles and procedures (Congressional Research Service, 1983; National Academy of Sciences, 1983; Office of Science and Technology, 1985). The risk assessment consisted of five components: hazard identification, exposure assessment, toxicity assessment, risk characterization, and uncertainty analysis.

In the hazard identification, the chemicals present were identified. This was done by conducting the test burn in the Bang Box facility at DPG and identifying and quantifying the chemicals present.

In the second step, the exposure assessment, the study area was defined, the potentially exposed population was identified, and exposure pathways were determined. The exposure pathways show how people might potentially have come into contact with a substance. This step also included estimating the concentration of each substance in each media (water, soil, air), and estimating the amount of substance to which each individual may have been exposed. Scenarios were developed that encompass the likely ways that people may have been exposed.

The toxicity assessment involved using toxicological databases to determine what levels of each chemical are known to cause health effects. In the risk characterization step, the exposure information was combined with the toxicity information to determine the risk of experiencing a health effect due to the propellant bag burning activity.

The uncertainty analysis summarizes how variability and uncertainty may affect the numbers generated in the risk assessment and the conclusions drawn.

The technical approach described in this protocol is designed to provide estimates of individual risk, and risk to the people most likely to be exposed. The HHRA was based upon current USEPA guidance and recommendations. This assessment provides a

conservative estimate of site risks and hazards. This approach includes the use of numerous default values, but where appropriate and defensible, the analysis used values more specific to the study area. In Appendix B, the values used are shown for each equation, along with a note indicating if it was a site-specific value.

The risk assessment methodology followed key USEPA guidance that included, but was not limited to:

- *Methodology for Assessing Health Risk Associated with Indirect Exposure to Combustor Emissions*. This document will be referred to as the Indirect Exposure Document (IED). 1990.

- *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. This document will be referred to as the Indirect Exposure Document Addendum (IEDA). 1993.

- *Revised Draft of Risk Assessment Implementation Guidance for Hazardous Waste Combustion Facilities*. This document will be referred to as the Implementation Guidance (IG). 1994.

- Errata Sheet, *Revised Draft of Risk Assessment Implementation Guidance for Hazardous Waste Combustion Facilities*. This document will be referred to as the Errata Sheet. 1994.

- *Risk Assessment for Superfund, Volume I, Human Health Evaluation Manual, Part A* (RAGS). 1989.

- *Exposure Factors Handbook*. 1997.

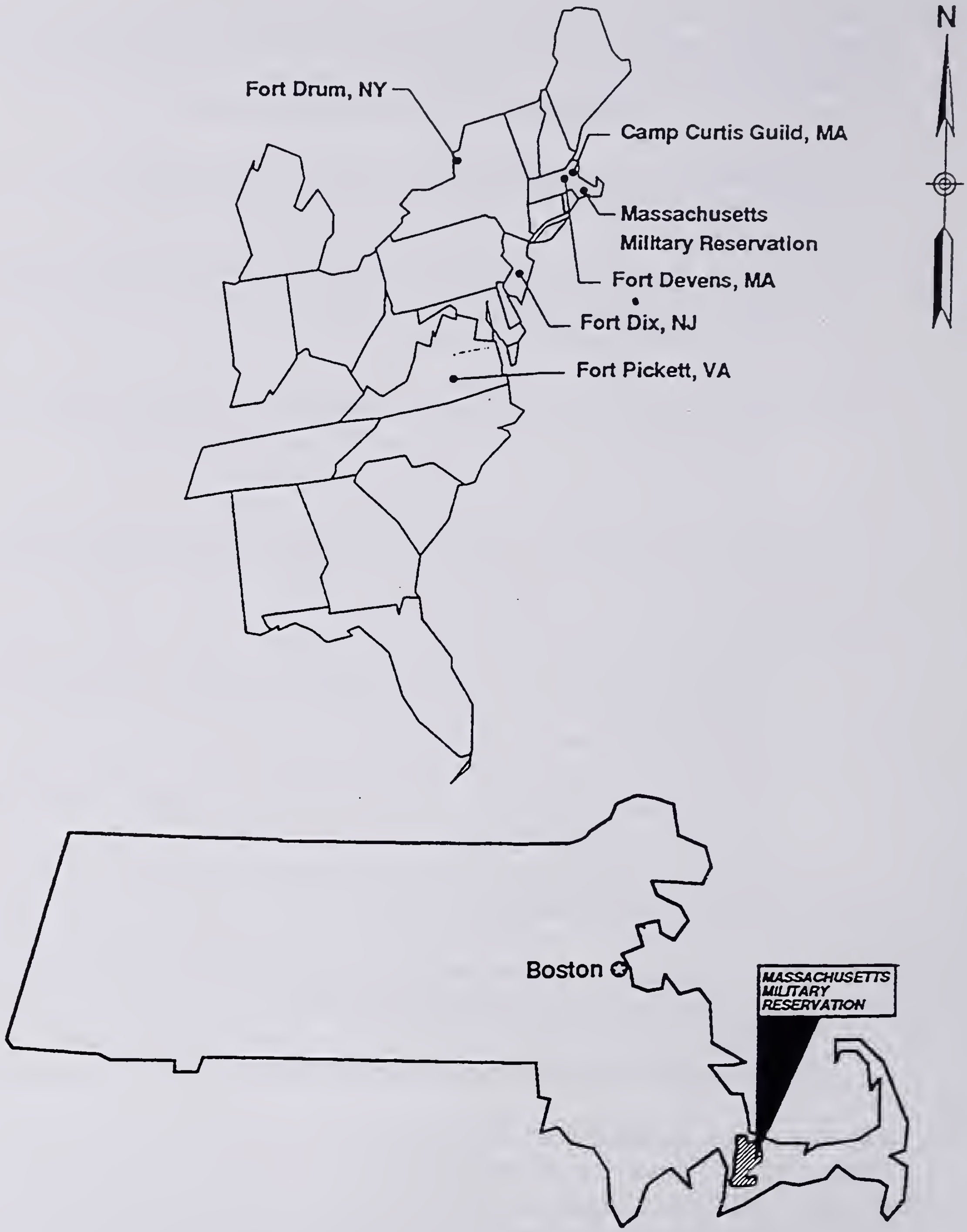
- *North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units*. 1997

1.3 Massachusetts Military Reservation Background

1.3.1 Location and Topography

Camp Edwards is part of MMR which is located in Upper Cape Cod, Massachusetts (see Figure 1-1). The MMR is a multi-purpose training installation that occupies approximately 22,000 acres on the western side of Cape Cod, in Barnstable County. The MMR lies within the towns of Bourne, Mashpee, Falmouth, and Sandwich (ATSDR, 1994). The reservation is approximately 60 miles south-southeast of Boston and immediately south of the Cape Cod Canal (ATSDR, 1994).

Figure 1-1



SITE LOCATION EVALUATION AND
MMR VICINITY MAP

1.3.2 History and Mission

Several military branches operate at MMR, including the U.S. Coast Guard (USCG), the MAANG, the U.S. Air Force (USAF), the Veterans Administration (VA), and the Massachusetts Air National Guard (ATSDR, 1994). Otis Air National Guard Base (OANGB) is located in the southern portion of MMR.

Military activity began at Cape Cod in 1911. Two types of operations have dominated military activity at MMR: mechanized army training, maneuvers, and maintenance support; and military aircraft operations, maintenance, and support. Most of the military activity has occurred since 1935 and has involved Army infantry maneuvers and aircraft operations. Currently, the military uses the facility for training. The USCG also launches search and rescue missions from the base (ATSDR, 1994).

The cantonment area (see Figure 1-2) has been the most actively used area of the reservation. During WW II, the Army used the cantonment area to service large motor pools (up to 400 vehicles). Levels of activity were highest in the cantonment between 1955 and 1972 when USAF surveillance and air defense units were stationed at MMR (ATSDR, 1994).

1.3.3 Facilities and Layout

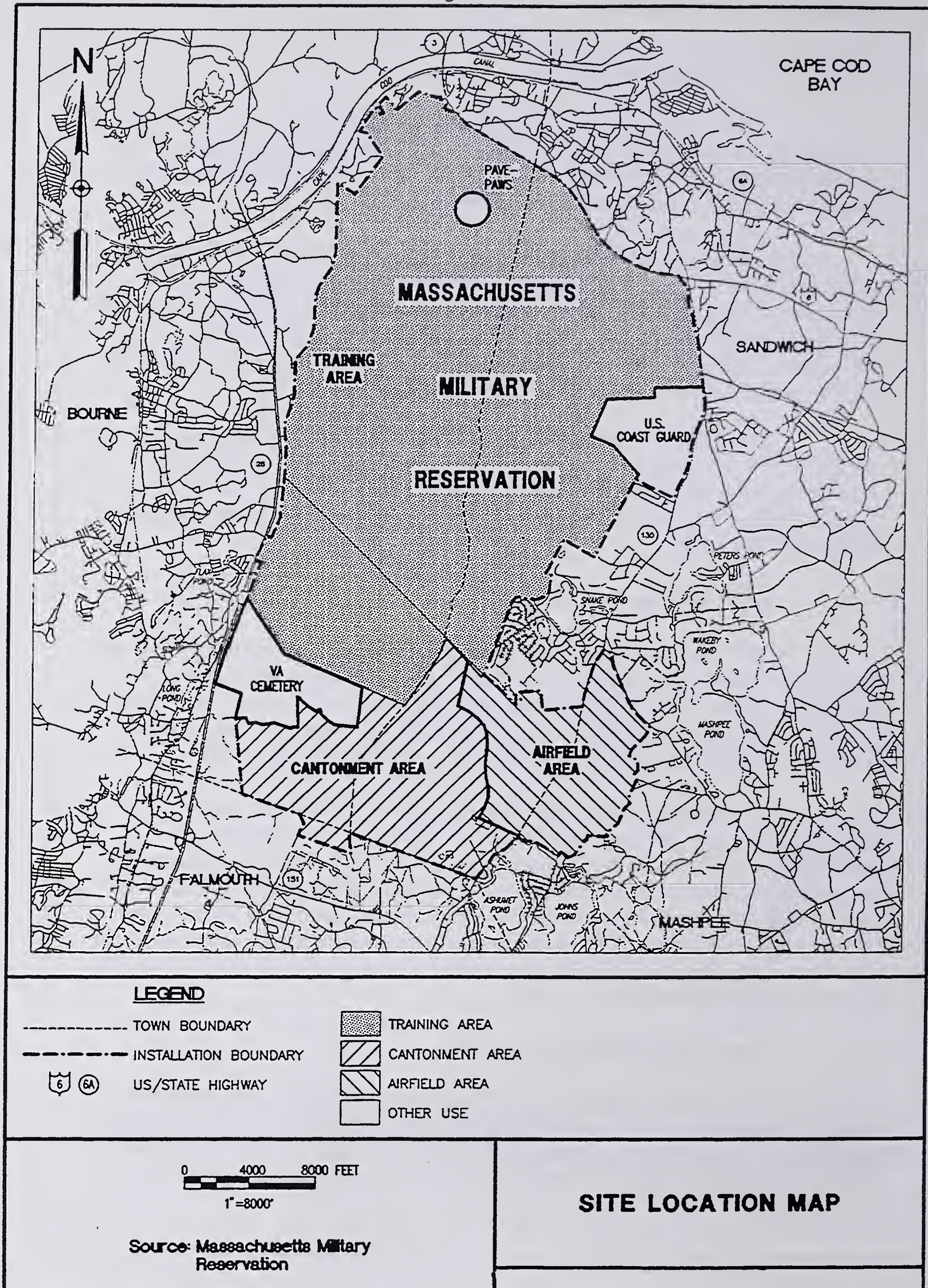
The majority of the facilities at MMR are located in the southern part of the installation. The northern 70 percent of MMR houses the artillery range and the maneuver and impact area of Camp Edwards, as well as the USCG Transmitter Facility and Cape Cod Air Force Station. Although several military branches operate at MMR, 90 percent of the land is owned by the State of Massachusetts (ATSDR, 1994).

The MMR is composed of three main areas: a 14,236 acre range, a maneuver area, and an impact area; a 750-acre VA cemetery, also known as Massachusetts National Cemetery is on the western edge of the reservation; and a 5,000-acre cantonment area on the southern portion of the MMR. The 87-acre Cape Cod Air Force Station, commonly known as Precision Acquisition Vehicle Entry-Phased Array Warning System (PAVE-PAWS), is also located in the northern portion of the range area (see Figure 1-2). The PAVE-PAWS radar facility has been used by the USAF since 1978 to detect sea-launched ballistic missiles.

1.3.4 Demographics and Land Use

The upper portion of Cape Cod is 212 square miles and encompasses the towns of Barnstable, Bourne, Falmouth, Mashpee, and Sandwich. The area had a 1990 population of 98,346. The population of the Upper Cape towns increased approximately 22 percent from 1980 to 1990. A large proportion of the population, (19.6% overall) is

Figure 1-2



N
CAPE COD BAY
CANAL
PAVE-PAWS
MASSACHUSETTS
MILITARY
RESERVATION
TRAINING AREA
SANDWICH
BOURNE
U.S. COAST GUARD
PETERS POND
SNAKE POND
WAKEBY POND
VA CEMETERY
LONG POND
MASHPEE POND
AIRFIELD AREA
CANTONMENT AREA
FALMOUTH
ASHUMET POND
JOHNS POND
MASHPEE
LEGEND
TOWN BOUNDARY
INSTALLATION BOUNDARY
US/STATE HIGHWAY
TRAINING AREA
CANTONMENT AREA
AIRFIELD AREA
OTHER USE
0 4000 8000 FEET
1"=8000'
Source: Massachusetts Military Reservation
SITE LOCATION MAP

persons aged 65 and older. The population of the entire Cape Cod area nearly triples during summers due to the influx of vacationers (ATSDR, 1994).

Approximately 2,400 people live in onpost housing and 1,150 people, both military and civilian, are full-time employees. Additionally, two contractors have full-time employees onsite. In order to carry out its function as an Air National Guard facility, OANGB employs approximately 1,200 part-time military personnel who work an average of 39 days each year.

Onpost residents live in the 631 family units on the southwestern portion of the reservation. Most of the housing area was built in the late 1950s. Occupied largely by Coast Guard families, it includes a grocery annex, a post exchange store, a gas station, and four schools. Three of these schools, Otis Memorial (grades K-3), Stone Middle School (grades 4-6), and Lyle School (grades 7 and 8), are part of the Bourne School Department. Approximately 1,000 students from both on and off post attend these schools. The fourth school is closed. There are two ponds (Osborne and Edmunds) and approximately 20 playgrounds located in the housing area. There is a golf course east of the housing area. In addition, a day care center and a health clinic are currently operating onpost (ATSDR, 1994).

Ground water is the major source of potable water in the area. Residential wells and several municipal supply wells are located in the Upper Cape. Three freshwater ponds south of the reservation are used for swimming, fishing, and boating. Ashumet Pond and Johns Pond are in the Briarwood neighborhood; Coonamessett Pond is west of these ponds. Snake and Weeks Ponds, located to the east of the installation, are used for recreational purposes (ATSDR, 1994).

Twenty percent of MMR is developed land. The remaining 80 percent is the artillery range, which is undeveloped. This area consists of gunnery areas and an artillery impact area. Vegetation in this area is periodically burned off for fire control (ATSDR, 1994).

1.4 Description of the Propellant Bag Burning Process

1.4.1 Background

Propellant bag burning was conducted by both U.S. Army National Guard and U.S. Army Reserve personnel as part of training exercises at MMR. The burning of artillery propellants which contain 2,4-dinitrotoluene (DNT) was stopped voluntarily in 1992. Each artillery and mortar round comes supplied with the standard maximum charge of propellant in a specific number of propellant bags. Because all artillery rounds come with the same number of propellant bags, they made not all be used to fire the round the correct distance. Manufacturers do not currently provide propellant packs for

restricted land use training; consequently, excess propellant bags were disposed of by burning.

1.4.2 Process Description

The excess propellant bags were collected each day at each firing point and were burned in the immediate proximity (USAEHA, 1987). Within the MMR training areas there are 11 separate mortar points where mortar propellant was burned and 16 separate gun points where artillery propellant was burned (see Figure 1-3). To burn the excess propellant, the unused bags (or charges) were typically arranged in lines ranging from 5 to 15 feet long and less than 1 foot wide (USAEHA, 1987). A small amount of propellant powder was laid at one end of the line to act as a fuse.

The burning of propellant bags involves the rapid oxidation of the propellants with a release of heat and products of combustion. When the bags are burned, there is a rapid conversion of solid materials into gaseous end products, particulate matter, and some non-volatilized residue. The composition of the emissions to the ambient air depends upon the type of propellant being burned, combustion parameters (e.g. temperature, turbulence), and atmospheric conditions (e.g. wind speed and humidity).

1.4.3 Types of Propellants Used at Camp Edwards

There are three primary categories of propellants: single-based, double-based, and triple-based. Single-based propellants are composed primarily of nitrocellulose, double-based propellants are composed primarily of nitrocellulose and nitroglycerin, and triple-based propellants are composed primarily of nitrocellulose, nitroglycerin, and nitroquanidine. Triple-based propellants were not used at Camp Edwards (MAARNG, 1994).

The single-based M1 propellant was used at Camp Edwards for firing artillery projectiles from the 155-mm Howitzer. Historically, this propellant was also used when firing the 105-mm howitzer. Table 1-1 presents the nominal composition of M1 propellant. The M1 propellant pack (called M3/green bags) used in the 155-mm howitzer is configured into five different charge bags. The five bags are different sizes and have slightly different chemical compositions (e.g., the first bag contains an igniter and bags four and five have a flash reducer (lead foil)). The M1 propellant pack (called M67) used in the 105-mm howitzer is configured into seven different charge bags. Again, the bags are different sizes and have slightly different chemical compositions (See Table 1-2). Because of the land use restrictions at MMR, normally only the first three charge bags were used when firing from the gun points surrounding the impact area. Therefore, charge bag numbers four and five for the 155-mm gun and charge bag numbers four through seven for the 105-mm gun were usually open burned at each of the gun points.

Figure 1-3. Firing Point Locations in the Camp Edwards Training Area

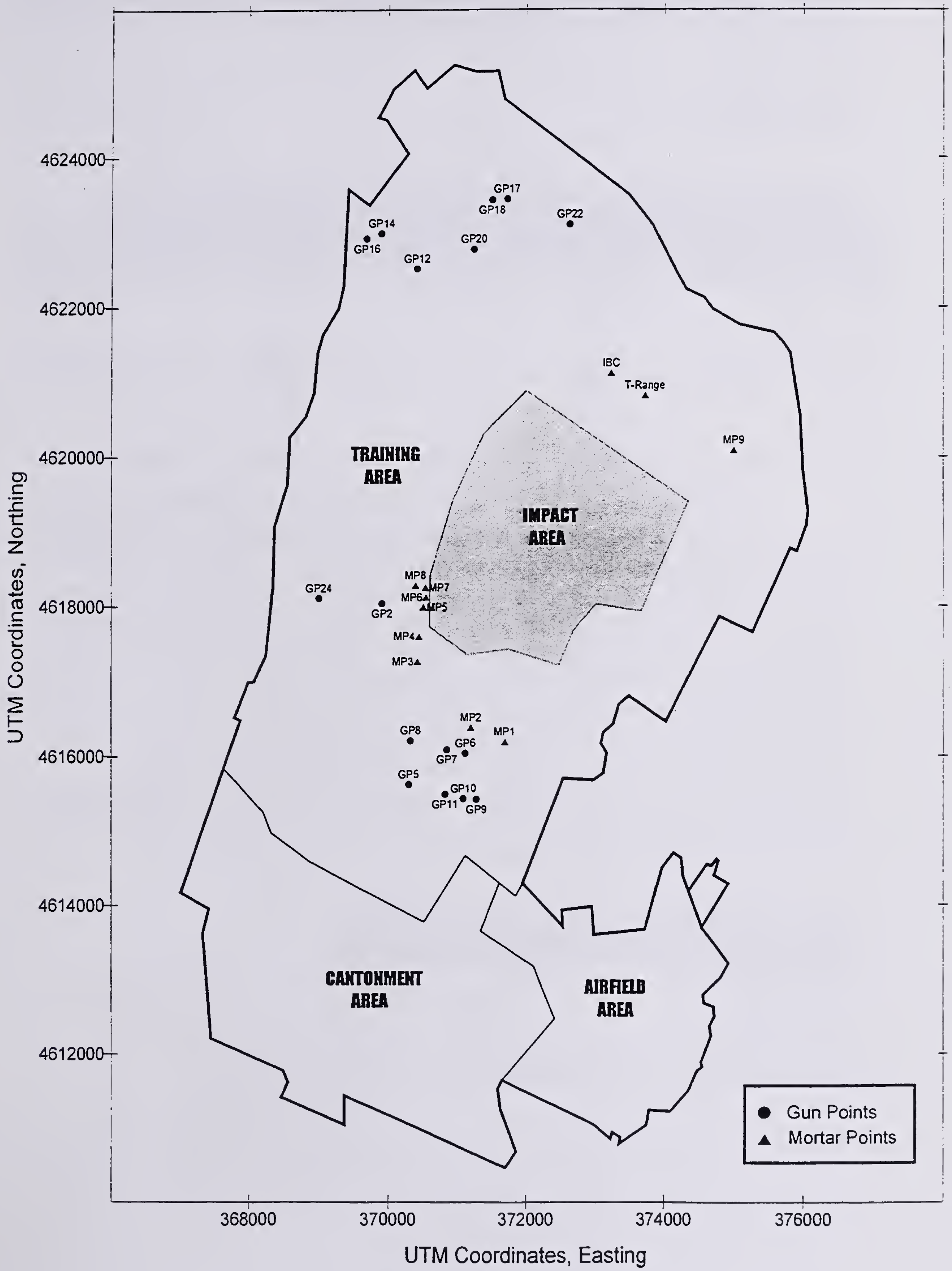


Table 1-1. Nominal Composition of M1 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	84.20
Dinitrotoluene	9.90
Dibutylphthalate	4.90
Diphenylamine	1.00

Table 1-2. Comparison of Howitzer charges (Both Contain M1 propellant)

Charge Number	*M67 (Used in 105 mm) Weight by charge (grams)*	*M3/Green Bags (Used in 155 mm) Weight by charge (grams)*
1	234.7	884.5
2	39.7	224.0
3	76.3	292.0
4	104.9	405.4
5	146.6	688.9
6	244.1	N/A
7	399.2	N/A

The double-based M9 propellant was used at Camp Edwards for firing 81-mm and 4.2-inch (107-mm) mortar cartridges. The similar, double-based M8 propellant was used for the 60-mm rounds and was also part of the propellant used for the 4.2-in mortars. Tables 1-3 and 1-4 present the nominal composition of M9 and M8 propellant, respectively. Table 1-5 contains the descriptions of the propellant packs included with the mortars that were used at Camp Edwards. The M9 propellant pack (called M90A1) is configured into nine charge increments (or bags) of the same size. Each bag is of similar chemical composition and contains approximately 10.5 grams of propellant. The M8 propellant pack (called M3A1, M181, or M182) is configured into four bags of equal weight and size. Each bag is of similar chemical composition and contains approximately 2.8 grams of propellant. The propellant pack for the 4.2-inch mortar is made up of 41 rectangular increments (referred to as "cheese") of equal size and weight. Each charge increment contains approximately 7.6 grams of propellant.

Table 1-3. Nominal Composition of M9 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	57.75
Nitroglycerin	40.00
Potassium Nitrate	1.50
Diphenylamine	0.75

Table 1-4. Nominal Composition of M8 Propellant

Compound	*Percentage of Total Weight*
Nitrocellulose	52.15
Nitroglycerin	43.00
Diethylphthalate	3.00
Potassium Nitrate	1.25
Ethylcentralite	0.60

Table 1-5. Mortars and Propellant Used at Camp Edwards

Mortar Type	*Propellant Type*	*Number of Increments*	*Weight Per Increment (grams)*	*Increment Configuration*
81-mm	M9	9	10.5	Bags
60-mm	M8	4	2.8	Bags
4.2-in (107-mm)	M9/M8	41	7.6	"Cheese"

Section 2

DETERMINATION OF AIR CONCENTRATION AND DEPOSITION RATES

2.0 DETERMINATION OF AIR CONCENTRATIONS AND DEPOSITION RATES

A fundamental part of this risk assessment was characterizing and modeling emissions from burning propellant at the gun and mortar points in the training areas of MMR. This involved collecting and characterizing onsite burn data, determining chemical-specific emission rates from the Bang Box burn trials, and modeling emissions from the each of the burn sites. The results from these steps were combined to determine air concentration and soil deposition rates. The following paragraphs describe these steps in more detail.

2.1 Propellant Burn Data

The propellant burn data was collected and characterized to determine an annual average of artillery (M1) and mortar (M9) propellant burned at the MMR firing points and to determine how often each firing point was utilized on an annual basis. Propellant burn information was collected from records kept by the MMR environmental office since 1986. These data (Appendix C, Tables C-2 to C-16) were organized by ammunition type (mortar or artillery), amount burned per year, and if known, firing point utilized. Because of the different chemical composition of artillery and mortar propellant, a separate health risk analysis was done for each type of propellant (M1 and M9). The health risks for both propellants were added together resulting in an overall health risk associated with exposure to propellant bag burning.

For the purposes of this study, all mortar propellant burned at Camp Edwards was considered to be M9 propellant, because the M8 propellant has a very similar chemical composition to M9 propellant (see Tables 1-3 and 1-4) and there is no emissions data for M8 propellant. Furthermore, all artillery propellant was assumed to be M1 propellant since M1 propellant is used for firing both the 105mm and 155mm howitzers—the only howitzers included in the firing records.

2.1.1 Annual Average of Propellant Burned at MMR

An annual average of all propellants burned at Camp Edwards is presented in Table 2-1 characterized as the M1 and M9 propellants. The burning of M1 propellant at Camp Edwards ceased in March 1992 and was not burned during January through March of that same year. The data records for 1987 and 1990 only included half of each year; therefore, the amounts recorded for those years were doubled to account for this lack of data.

2.1.2 Annual Average Firing Point Utilization

An annual average of firing point utilization is shown in Tables 2-2 and 2-3. The percentages in the tables represent the fraction of total propellant burned at Camp Edwards at each firing point. The data records for 1987 and 1988 did not include firing point utilization. The average firing point utilization was combined with the overall average propellant burned annually to determine an average amount of propellant burned at each site.

Table 2-1. Annual Propellant Burned at Camp Edwards

Year	*M1 Propellant (lbs)*	*M9 Propellant (lbs)*
1986	10631	952
1987	6715*	291*
1988	2712	324
1989	4029	1699
1990	2978*	259*
1991	3893	1595
1992	0	425
1993	0	692
1994	0	292
Annual Average	**5160** (Based on 6 years)	**725** (Based on 9 years)

* Double the amount found in the records to account for lacking data

Table 2-2. Annual Gun Point Utilization at Camp Edwards*

Gun Point	*1986*	*1989*	*1990*	*1991*	*Annual Avg.*
GP2	0.0%	0.0%	0.0%	0.0%	0.0%
GP5	0.0%	0.0%	0.0%	0.0%	0.0%
GP6	13.4%	8.9%	16.7%	18.1%	14.3%
GP7	8.8%	7.5%	25.5%	6.3%	12.0%
GP8	9.9%	4.2%	4.5%	6.9%	6.4%
GP9	15.4%	6.8%	6.5%	9.9%	9.6%
GP10	8.7%	9.7%	6.2%	8.5%	8.3%
GP11	6.4%	8.6%	0.0%	7.7%	5.7%
GP12	0.8%	4.5%	0.0%	3.1%	2.1%
GP14	7.3%	6.7%	11.5%	10.2%	8.9%
GP16	8.2%	10.9%	4.7%	5.6%	7.4%
GP17	0.8%	2.6%	0.0%	3.9%	1.8%
GP18	3.1%	2.6%	7.2%	0.0%	3.2%
GP20	8.4%	13.0%	13.0%	10.6%	11.2%
GP22	6.6%	14.0%	4.2%	8.1%	8.2%
GP24	2.2%	0.0%	0.0%	1.1%	0.9%

* Percentage based upon total amount of propellant burned for each year

Table 2-3. Annual Mortar Point Utilization at Camp Edwards*

Mortar Point	*1986*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*Annual Avg.*
MP1	6.9%	6.1%	24.9%	23.6%	10.4%	9.8%	12.0%	13.4%
MP2	10.0%	25.4%	2.9%	0.7%	10.9%	2.8%	16.9%	10.0%
MP3	39.4%	16.7%	12.1%	34.8%	19.2%	30.5%	21.8%	24.9%
MP4	10.8%	29.5%	4.7%	14.6%	19.8%	24.3%	12.0%	16.5%
MP5	4.8%	7.8%	0.0%	0.0%	4.9%	3.1%	0.0%	2.9%
MP6	21.8%	4.8%	11.0%	7.8%	6.6%	13.4%	15.4%	11.6%
MP7	4.4%	5.5%	31.2%	8.9%	5.5%	1.9%	8.2%	9.4%
MP8	0.0%	4.2%	10.1%	3.3%	22.6%	14.2%	13.7%	9.7%
MP9	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
IBC	0.0%	0.0%	0.0%	3.7%	0.0%	0.0%	0.0%	0.6%
T-Range	1.7%	0.0%	3.1%	2.2%	0.0%	0.0%	0.0%	1.0%

* Percentage based upon total amount of propellant burned for each year

2.1.3 Annual Average Burn Rates from Each Firing Point

Tables 2-4 and 2-5 include the annual average of propellant burned for each site as determined from the overall propellant burned and the average utilization of each firing point. Each table also contains the annualized burn rate of propellant which was used to determine the chemical-specific emission rate from each of the firing points. Because there was no propellant burned at GP2, GP5, and MP9 during the study period, 1985-1991, these firing points would not have made any contribution to the overall concentration and deposition rates, and therefore, were not included in the evaluation.

Table 2-4. Annual Burn Rates at Each Gun Point.

Gun Point	*Average Utilization*	*Annual Average of Propellant Burned (lbs)*	*Annualized Burn Rate of Propellant (g/s)*
GP2	0.0%	0	0
GP5	0.0%	0	0
GP6	14.3%	738	1.06E-02
GP7	12.0%	620	8.92E-03
GP8	6.4%	330	4.75E-03
GP9	9.6%	496	7.13E-03
GP10	8.3%	429	6.17E-03
GP11	5.7%	295	4.24E-03
GP12	2.1%	109	1.57E-03
GP14	8.9%	460	6.62E-03
GP16	7.4%	382	5.49E-03
GP17	1.8%	93	1.34E-03
GP18	3.2%	165	2.37E-03
GP20	11.2%	578	8.31E-03
GP22	8.2%	423	6.08E-03
GP24	0.9%	42	6.04E-04
Total:	100.0%	5160	7.42E-02

Table 2-5. Annual Burn Rates at Each Mortar Point.

Mortar Point	*Average Utilization*	*Annual Average of Propellant Burned (lbs)*	*Annualized Burn Rate of Propellant (g/s)*
MP1	13.4%	97	1.40E-03
MP2	10.0%	73	1.05E-03
MP3	24.9%	181	2.60E-03
MP4	16.5%	120	1.73E-03
MP5	2.9%	21	3.02E-04
MP6	11.6%	84	1.21E-03
MP7	9.4%	68	9.78E-04
MP8	9.7%	70	1.01E-03
MP9	0.0%	0	0
IBC	0.6%	4	5.75E-05
T-Range	1.0%	7	1.01E-04
Total:	100.0%	725	1.04E-02

2.2 Chemical-Specific Emission Rates

A chemical-specific emission rate from burning M1 and M9 propellant was determined for each of the chemicals that were identified and quantified in the Bang Box burn trials. The emission rates were calculated using the annual average burn rates determined from the historical propellant burn data and the emission factors determined from the burn trials.

2.2.1 Bang Box Burn Trials

To characterize the emissions associated with propellant burning, a series of propellant burns were conducted between 16-18 March 1993 in the Bang Box facility at Dugway Proving Ground (DPG). The DPG Bang Box facility is a permitted test facility specifically designed for the burning/detonation of small quantities of propellants/explosives. During the controlled tests in the Bang Box facility, DPG personnel burned the same propellant bags that are normally burned at Camp Edwards while replicating the temperature and relative humidity typical of Camp Edwards (MAANG, 1994). Separate tests were conducted burning M1 propellant (used in artillery firing) and M9 propellant (used in mortar firing). Because triple-based propellants were not used at Camp Edwards, they were not used in the Bang Box analysis.

The burns were conducted in accordance with a detailed test plan prepared by the U.S. Army Environmental Hygiene Agency (USAEHA, 1993). The test plan was reviewed extensively by the Massachusetts Department of Environmental Protection (MADEP), Massachusetts Department of Public Health (MADPH), and EPA Region I prior to acceptance. Representatives from the EPA Region I, MADEP, MADPH, and the Barnstable County Health Department were onsite to witness the test and verify that air sampling was conducted properly. The following paragraphs describe the sampling methodology used to characterize the emissions from the DPG Bang Box facility.

Prior to testing, background sampling was conducted to identify any indigenous ambient contaminants which may have been present in the Bang Box facility. During the 3 days of test burns, six burn trials were conducted; five trials were used to determine emissions from burning M1 propellant and one trial was used to determine emissions from burning M9 propellant (MAARNG, 1994). The volatile organic compounds (VOCs) were collected using 6-liter stainless steel canisters. Five VOC samples were obtained for the M1 propellant burns and one sample was obtained for the M9 propellant burn. For metals emissions, three high volume (HiVol) samplers were used for each trial. Fifteen metals samples were taken during the M1 propellant burns and three samples were taken during the M9 propellant burn. The semivolatile organic compounds (SVOCs) were collected using two separate sampling methods: three HiVol samplers and three PS-1 samplers. Thirty SVOC samples were taken during the five M1 propellant burns and six samples were taken during the M9 propellant burn. The hydrogen chloride (HCl) and hydrogen cyanide (HCN) sampler measured HCl during the M9 propellant burn and the first M1 propellant burn and measured HCN during the last four M1 propellant trials. PM_{10} was sampled during all six burns.

Two different analytical methods were used to measure the concentrations of the SVOCs. The EPA Method 8270 (gas chromatograph/mass spectrometer) was used as the general analytical method while supercritical fluid chromatography/mass spectrometry was used for specific, thermally liable compounds like RDX, HMX, 2,4-DNT, and 2,4,6-TNT. The combination of two different samplers and two different analytical methods used to identify SVOC emissions resulted in as many as 45 samples for certain compounds.

2.2.2 Calculating Chemical-Specific Emission Factors

The list of chemicals that were identified and quantified in the Bang Box burn trials for both M1 and M9 propellants is shown in Table 2-6. To characterize the chemical emissions from the burning of both propellants, an emission factor, and eventually an emission rate, was calculated for all of the chemicals listed in Table 2-6.

An emission factor was calculated for each chemical every time it was detected in a valid sample. In cases when more than one sample was analyzed, an overall emission factor for each chemical was determined by averaging the emission factors calculated from each sample. If the sample was analyzed with more than one method, as was the case with some SVOCs, the higher average emission factor was chosen. The emission factors contained in the emissions characterization report (MAANG, 1994) were verified by recalculating the factors from the raw data found in the report. Table 2-6 also contains the emission factors from burning both M1 and M9 propellant which were determined from the Bang Box burn trials.

The emissions characterization report included data for unidentified VOCs and tentatively identified SVOCs. For the purposes of including the quantified amounts of the unidentified VOCs, the emission factors for the identified VOCs were marked up by the appropriate percentage of unknown compounds. As seen in Equation 2-1, the mark-up factors were calculated for each of the six trials by dividing the total *identified* hydrocarbons into the total hydrocarbons detected. This methodology basically assigns the overall average toxicity of the identified compounds to the compounds which were unidentified.

Equation 2-1:

$$Mark-up\ Factor = \frac{Total\ Identified\ Hydrocarbons + Total\ Unidentified\ Hydrocarbons}{Total\ Identified\ Hydrocarbons}$$

The VOCs identified during the M9 propellant burn were marked up by a factor of 1.86. The VOCs identified during the five M1 propellant burns were marked up by factors of 1.29, 2.31, 1.52, 1.21, and 1.46, respectively. The emission factors for VOCs shown in Table 2-6 include this adjustment to account for the unidentified hydrocarbons that were detected in the sampling analysis.

Most of the tentatively identified SVOCs were reported as analytical contaminants or background constituents of the Bang Box. Benzonitrile, though, was tentatively identified in

more than half of the samples and was not considered an analytical contaminant. Therefore, it was added as an SVOC to the chemical list in Table 2-6 and included in the risk assessment.

Table 2-6. Chemical-Specific Emission Characteristics

Chemical Type	M1 Propellant Emission Factor (wt/wt)*	M9 Propellant Emission Factor (wt/wt)*	M1 Propellant Emission Rates (g/s)	M9 Propellant Emission Rates (g/s)	Particulate Fraction (%)	Vapor Fraction (%)
Volatile Organics						
Benzene	1.94E-05	6.06E-06	1.44E-06	6.32E-08	0.00%	100.00%
Carbon Tetrachloride	8.59E-07	4.96E-07	6.37E-08	5.17E-09	0.00%	100.00%
Ethylbenzene†	3.34E-07	0.00E+00	2.48E-08	0.00E+00	0.00%	100.00%
Methane†	4.46E-05	0.00E+00	3.31E-06	0.00E+00	0.00%	100.00%**
n-Propylbenzene†	2.18E-07	0.00E+00	1.62E-08	0.00E+00	0.00%	100.00%
Styrene#	0.00E+00	8.78E-07	0.00E+00	9.15E-09	0.00%	100.00%
Toluene†	2.76E-06	0.00E+00	2.05E-07	0.00E+00	0.00%	100.00%
m&p-Xylene†	2.07E-07	0.00E+00	1.54E-08	0.00E+00	0.00%	100.00%
o-Xylene†	1.18E-06	0.00E+00	8.75E-08	0.00E+00	0.00%	100.00%
Semivolatile Organics						
Acenaphthylene	4.81E-07	8.06E-08	3.57E-08	8.40E-10	0.00%	100.00%
Acetophenone	2.09E-06	3.65E-06	1.55E-07	3.81E-08	0.00%	100.00%
4-Aminobiphenyl†	3.51E-07	0.00E+00	2.61E-08	0.00E+00	0.00%	100.00%
Benzo[a]anthracene†	8.79E-09	0.00E+00	6.52E-10	0.00E+00	97.48%	2.52%
Benzo[a]pyrene	7.71E-09	3.78E-09	5.72E-10	3.95E-11	60.00%	40.00%**
Benzo[b]fluoranthene†	1.97E-08	0.00E+00	1.46E-09	0.00E+00	27.93%	72.07%
Benzo[ghi]perylene†	9.87E-09	0.00E+00	7.33E-10	0.00E+00	49.21%	50.79%
Benzoic Acid†	3.05E-07	0.00E+00	2.26E-08	0.00E+00	0.01%	99.99%
Benzonitrile	1.09E-05	1.51E-05	8.06E-07	1.57E-07	0.00%	100.00%
Bis(2-Ethylhexyl)phthalate	3.80E-06	5.79E-08	2.82E-07	6.03E-10	20.00%	80.00%**
Butyl benzyl phthalate	1.67E-07	1.57E-07	1.24E-08	1.64E-09	20.00%	80.00%**
Di-n-butyl phthalate	8.75E-06	1.86E-06	6.49E-07	1.94E-08	20.00%	80.00%**
Di-n-octyl phthalate	8.65E-08	3.01E-07	6.42E-09	3.14E-09	20.00%	80.00%**
Dibenzofuran	7.73E-08	1.56E-08	5.73E-09	1.63E-10	20.00%	80.00%**
Diethyl phthalate	1.83E-06	6.54E-06	1.36E-07	6.82E-08	20.00%	80.00%**
Dimethyl phthalate	3.44E-07	5.20E-07	2.55E-08	5.42E-09	20.00%	80.00%**
a,a-Dimethylphenethylamine	2.02E-07	1.59E-07	1.50E-08	1.66E-09	0.00%	100.00%
2,4-Dimethylphenol†	6.06E-07	0.00E+00	4.50E-08	0.00E+00	0.00%	100.00%
2,4-Dinitrotoluene†	6.21E-06	0.00E+00	4.61E-07	0.00E+00	0.00%	100.00%**
Diphenylamine	5.66E-09	1.22E-09	4.20E-10	1.27E-11	2.97%	97.03%
Fluoranthene†	2.26E-07	0.00E+00	1.68E-08	0.00E+00	98.51%	1.49%
HMX†	3.45E-10	0.00E+00	2.56E-11	0.00E+00	0.19%	99.81%
2-Methylnaphthalene	2.39E-07	1.19E-07	1.78E-08	1.24E-09	0.00%	100.00%
N-Nitrosodiphenylamine	2.68E-08	1.58E-08	1.99E-09	1.65E-10	0.00%	100.00%
Naphthalene	9.97E-07	4.60E-07	7.40E-08	4.80E-09	0.00%	100.00%
2-Nitrodiphenylamine†	3.22E-09	0.00E+00	2.39E-10	0.00E+00	0.00%	100.00%
2-Nitrophenol	3.82E-07	1.19E-06	2.83E-08	1.24E-08	0.00%	100.00%
4-Nitrophenol	2.58E-07	9.63E-07	1.92E-08	1.00E-08	0.00%	100.00%
2-Nitropyrene	6.99E-10	6.21E-09	5.18E-11	6.47E-11	21.68%	78.32%
Phenacetin†	3.24E-07	0.00E+00	2.40E-08	0.00E+00	0.19%	99.81%
Phenanthrene	2.65E-07	1.57E-07	1.97E-08	1.64E-09	0.00%	100.00%

Phenol†	2.01E-06	0.00E+00	1.49E-07	0.00E+00	0.00%	100.00%
Pyrene†	1.60E-07	0.00E+00	1.19E-08	0.00E+00	0.00%	100.00%
RDX	1.25E-08	1.08E-09	9.31E-10	1.12E-11	22.05%	77.95%
1,2,4-Trichlorobenzene	0.00E+00	1.25E-07	0.00E+00	1.31E-09	0.00%	100.00%
2,4,6-Trinitrotoluene†	1.22E-08	0.00E+00	9.06E-10	0.00E+00	0.00%	100.00%
Metals						
Aluminum	9.81E-06	4.39E-06	7.28E-07	4.57E-08	100.00%	0.00%
Cadmium	1.59E-07	6.01E-07	1.18E-08	6.26E-09	100.00%	0.00%**
Calcium	4.29E-05	7.30E-05	3.18E-06	7.62E-07	100.00%	0.00%
Copper	4.23E-06	6.46E-06	3.14E-07	6.74E-08	100.00%	0.00%
Lead	4.07E-06	1.00E-06	3.02E-07	1.05E-08	100.00%	0.00%**
Mercury†	1.44E-08	0.00E+00	1.07E-09	0.00E+00	0.00%	100.00%**
Potassium	3.03E-03	5.24E-03	2.25E-04	5.46E-05	91.57%	8.43%
Sodium	5.08E-05	6.38E-05	3.77E-06	6.66E-07	99.99%	0.01%
Titanium	3.82E-07	2.64E-07	2.83E-08	2.75E-09	100.00%	0.00%
Zinc†	9.68E-06	0.00E+00	7.18E-07	0.00E+00	100.00%	0.00%
Acids and Particulate						
HCl	7.40E-05	7.54E-05	5.49E-06	7.86E-07	0.00%	100.00%
HCN†	1.47E-04	0.00E+00	1.09E-05	0.00E+00	0.00%	100.00%
PM10	8.68E-03	1.55E-02	6.44E-04	1.62E-04	100.00%	0.00%**

* Weight of chemical PER weight of propellant burned

† Compound not detected in M9 propellant burns

\# Compound not detected in M1 propellant burns

** These vapor fractions were provided by the USEPA (USEPA 1994a)

2.2.3 Calculating Chemical-Specific Emission Rates

The chemical-specific emission rate was calculated by multiplying the propellant burn rate by a specific chemical emission factor as shown in Equation 2-2:

Equation 2-2:

$$\mathit{Chemical\ Emission\ Rate}\,(g/s) = \mathit{Chemical\ Emission\ Factor}\,(g/g) * \mathit{Propellant\ Burn\ Rate}\,(g/s)$$

To obtain an overall emission rate which includes contributions from each of the mortar or gun points, the individual burn rates were summed from each mortar point or gun point, and that sum was multiplied by the chemical-specific emission factor (Equation 2-3). The overall chemical-specific emission rates for both M1 and M9 propellant are listed in Table 2-6.

Equation 2-3:

$$\mathit{Overall\ Chemical\ Emission\ Rate} = \mathit{Chemical\ Emission\ Factor} * \sum \mathit{Propellant\ Burn\ Rates}$$

2.3 Air Dispersion and Surface Deposition Modeling

The goal of the chronic modeling effort is to estimate concentrations and depositions that are as realistic as possible without underestimating risks. The tool used in this assessment to model emissions from the past propellant bag burning activities at Camp Edwards was the latest version (97363) of the Industrial Source Complex Short Term (ISCST3) model. This USEPA

developed model is a steady-state Gaussian dispersion plume model which is capable of handling inputs of multiple sources, hourly meteorological data, and digitized terrain data. This model was chosen specifically because of its ability to estimate dry deposition and wet deposition values as well as ambient air concentrations for each source and receptor combination during each hour of meteorological data. The model assumes continuous operations, and although the burning activity did not happen continuously, the modeling results were less affected by this approach because the model calculates annual averages for concentrations and depositions. In fact, this approach was conservative by including the nighttime meteorological conditions (which return higher concentrations) and by modeling all of the gun or mortar points as burning at the same time. The following paragraphs describe the receptor locations where concentration and deposition calculations were made, the meteorological data that was used in the model, and the model inputs used to calculate concentration and deposition rates.

2.3.1 Receptor Locations and Population Scenarios

Chemical-specific concentration and deposition rates were calculated for specific locations, or receptors, around the MMR. For each receptor location, five media concentrations were calculated: particulate dry and wet deposition (P_{dd} and P_{wd}), particulate air concentration (P_c), vapor wet deposition (V_{wd}), and vapor air concentration (V_c). These concentration and deposition rates will be referred to as C/DRs throughout the rest of this report.

Among the receptors included in the model runs were fenceline receptors, an offsite Cartesian grid, and onsite discrete receptors. The fenceline receptors were placed at 100 m intervals along the entire installation fenceline. A tighter fenceline grid of 25 m intervals was placed around the preliminary maximum found at 100 m intervals to further refine the maximum concentration and deposition rates at the fenceline. A Cartesian receptor grid was placed outside of the installation boundary in order to calculate offsite isopleths[1]. This receptor grid covers over 5 km from the boundary in all directions at 500 m spacing. Figure 2-1 presents both the fenceline and offsite receptor locations. The discrete receptors were placed at onsite residential housing areas, onsite schools, specific waterbodies and their respective watershed area, and various MMR work sites. These discrete receptor locations are listed in Table 2-7 and shown in Figure 2-2. The watershed areas associated with the pairs of waterbodies listed in Table 2-7 are marked as a polygon surrounded with a solid line in Figure 2-2. The receptor locations within each of the five watershed areas were spaced evenly throughout the polygon as presented on Figure 2-2.

[1] The health-risk based isopleths have not been calculated as of the printing of this draft report. The isopleth calculations do not affect the final outcome of the health risk assessment, but they will supply extra information about C/DRs outside of the MMR boundary. The health-risk based isopleth information will be completed for the final report.

Figure 2-1. Fenceline and Offsite Cartesian Grid Receptor Locations

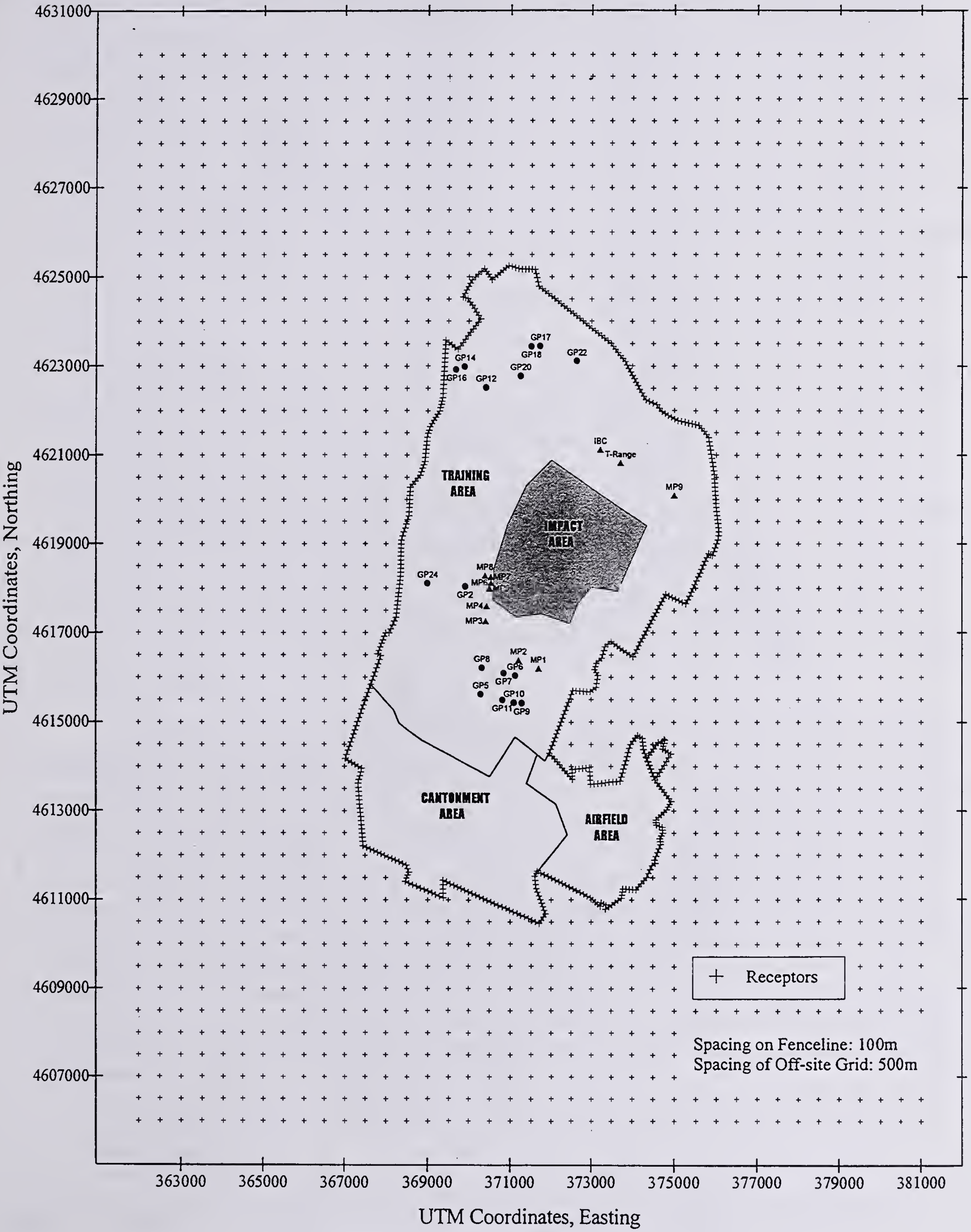


Figure 2-2. Onsite and Discrete Receptor Locations

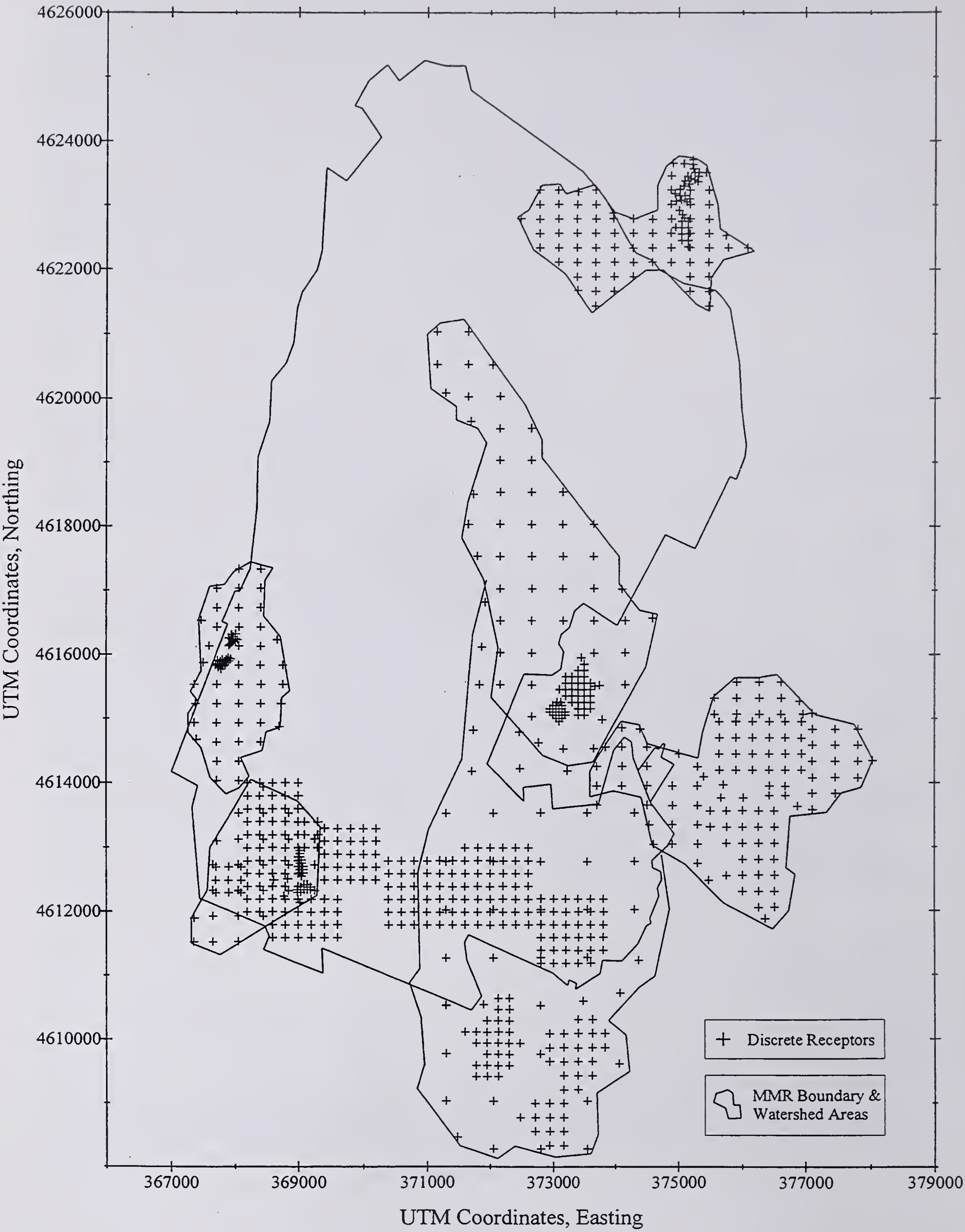


Table 2-7. Discrete Receptor Locations Around the MMR

Receptor Location	*UTM Coordinate (Easting)*	*UTM Coordinate (Northing)*	*Elevation (meters)*
J.H. Lyle School	368620	4612500	31.1
Otis Memorial School	368780	4612250	33.3
Stone School	368840	4612520	35.7
Campbell School	369030	4612150	27.7
Osborn Pond[1]	369050*	4612710*	15.8
Edmunds Pond[1]	369090*	4612350*	15.8
Rod & Gun Pond, N.[2]	367970*	4616220*	14.0
Rod & Gun Pond, S.[2]	367800*	4615860*	14.0
Snake Pond[3]	373400*	4615450*	21.0
Weeks Pond[3]	373090*	4615100*	21.0
Shawme Lake[4]	375100*	4623370*	8.6
Upper Shawme Lake[4]	375050*	4622640*	7.9
Ashumet Pond[5]	372125*	4609950*	13.1
Johns Pond[5]	373400*	4609440*	11.9
Wakeby Pond[6]	376680*	4614700*	17.1
Mashpee Pond[6]	376000*	4613070*	17.1
Onsite Housing Area	367700-369500#	4611600-4614000#	~ 37
Onsite Work Area Grid 1	369400-370200#	4612500-4613300#	~ 32
Onsite Work Area Grid 2	370400-372600#	4611800-4613000#	~ 35
Onsite Work Area Grid 3	372800-373800#	4611200-4612200#	~ 32

1,2,3,4,5,6 Superscripts refer to waterbodies that have been grouped together under the same watershed area
* Multiple receptors forming a lake-shaped grid centered around this coordinate
\# Rectangular Grid Limits

As described in Table 2-8, the appropriate C/DR for each of the population scenarios evaluated was used to determine exposures and chronic health risks. All of the offsite scenarios were evaluated using the maximum C/DR that occurs at the fenceline. The onsite scenarios (including schools, worksites, and housing areas) had a specific receptor (or small receptor grid) placed at their locations. The maximum C/DR for all of the onsite schools was used to evaluate the onsite student, the maximum C/DR for all of the MMR cantonment work sites was used to evaluate the onsite worker, and the maximum C/DR found in the housing areas was used to evaluate the onsite resident. The recreational fisher and recreational swimmer scenarios were evaluated using a receptor grid that covers the specific waterbody and watershed area. The average C/DR in the specific watershed area and waterbody was used to evaluate the fishers and swimmers (both on- and offsite). The recreational gardener was evaluated using the maximum C/DR at the fenceline because those results were greater than the C/DRs at the onsite housing areas.

Table 2-8. Scenario Specific Concentration and Deposition Rates

Scenario	*Receptor Description*	*How Evaluated*
Offsite Resident	Fenceline	Maximum
Offsite Worker	Fenceline	Maximum
Offsite Student	Fenceline	Maximum
Onsite Resident	Discrete Grids	Maximum
Onsite Worker	Discrete Grids	Maximum
Onsite Student	Discrete	Maximum
Recreational Fisher	Discrete Grids	Average
Recreational Swimmer	Discrete Grids	Average
Recreational Gardener	Fenceline	Maximum

2.3.2 Meteorological and Terrain Data

Site-specific meteorological conditions (e.g., wind speed, wind direction, air temperature, precipitation) were necessary for the model to calculate hourly C/DRs. The meteorological data was obtained from the Air Force Combat Climatology Center in Asheville, North Carolina which is the military equivalent to the civilian National Climatic Data Center. Surface data and precipitation data were compiled from the local met station at Otis Air National Guard Base for the 7-year period 1985-1991. Upper air data was compiled from Chatham, Massachusetts for the years 1985-86; 1988-1991. Upper air data from Albany, New York was used for 1987 because the Chatham station did not have data for 1987. The meteorological windroses depicting wind directions for each modeled year are provided in Appendix F.

A complete meteorological set was created using the USEPA preprocessor, PCRAMMET, which combines the surface, precipitation, and upper air data to generate a usable ISCST3 ASCII file. For this evaluation, PCRAMMET required the site-specific parameters that are listed in Table 2-9 to process the data appropriately, and the resulting meteorological file was then used to model transport of the smoke plume. The model calculated C/DRs for every hour of meteorological data, and those hourly C/DRs were averaged over the 7-year time period to obtain annual C/DRs.

Table 2-9. MMR Input Parameters for PCRAMMET

Input Parameters	*Value*
Latitude	41.650
Longitude	70.517
Time Zone	5
Minimum Monin-Obukhov Length	2.0
Anemometer Height	10.0
Surface Roughness Length at Measurement Site*	0.05, 0.10, 0.05, 0.05
Surface Roughness Length at Application Site*	0.40, 0.50, 0.40, 0.30
Noon Time Albedo*	0.13, 0.16, 0.15, 0.45
Bowen Ratio*	0.50, 0.40, 0.80, 1.50
Anthropogenic Heat Flux	0.00
Fraction of Net Radiation Absorbed at the Ground	0.15

* This parameter is seasonal. Presented here in order of Spring, Summer, Autumn, Winter

Because training at the MMR is seasonal, the model was configured to include only the meteorological data for the days that bag burning most often occurred. This resulted in a more accurate use of the annual meteorological data to account for changes in wind conditions and temperatures among the seasons. During the days that were evaluated, the model treated the burning activity as though it happened continuously; therefore, both nighttime and daytime meteorological conditions were included.

Tables 2-10 and 2-11 contain the monthly burn totals found in the records covering the 10-year study period, 1985-1994. As seen in these tables, certain months were either not included or were partially included in the C/DR calculations because no burning or very little burning occurred in those months between 1985-1994. This study period is most likely a good representation of the seasonal training pattern at Camp Edwards.

Based upon the highest monthly total for each type of propellant (March for M1 propellant; June for M9 propellant), a percentage of monthly burning occurrences has been calculated and is shown in the third column of the tables. From these percentages, the number of days in a month that burning occurred was determined. If the number of days was 10 or more, then the entire month was modeled, and if the number of days was between 1 and 9, then 7 nonconsecutive days were modeled for that month.

Table 2-10. Monthly Burn Data of Artillery Propellant for Years 1985-1991*

Month	*M1 Propellant Burned (lbs)*	*% Occurrence of Burning†*	*# of Days in a Month Represented‡*	*# of Days in the Month to be Modeled*
January	746	12.7 %	4	7
February	2165	36.7 %	11	28 (or 29)
March	5894	100.0 %	31	31
April	3476	59.0 %	18	30
May	3361	57.1 %	18	31
June	4094	69.5 %	22	30
July	0	0.0 %	0	0
August	0	0.0 %	0	0
September	2081	35.3 %	11	30
October	3336	56.6 %	18	31
November	1776	30.1 %	9	30
December	0	0.0 %	0	0

* There were no monthly totals available for 1989 (See Table C-8 in Appendix C).

† Based upon the highest monthly total (i.e., March).

‡ Based on 31 days in a month.

Table 2-11. Monthly Burn Data of Mortar Propellant for Years 1985-1994*

Month	*M9 Propellant Burned (lbs)*	*% Occurrence of Burning†*	*# of Days in a Month Represented‡*	*# of Days in the Month to be Modeled*
January	155	10.3 %	3	7
February	54	3.6 %	1	7
March	96	6.4 %	2	7
April	337	22.3 %	7	7
May	738	48.8 %	15	31
June	1512	100.0 %	31	30
July	681	45.1 %	14	31
August	464	30.7 %	10	31
September	277	18.3 %	6	7
October	154	10.2 %	3	7
November	363	24.0 %	7	7
December	0	0.0 %	0	0

* There were no monthly totals available for 1989 (See Table C-9 in Appendix C).
† Based upon the highest monthly total (i.e., June).
‡ Based on 31 days in a month.

Digitized terrain data of the upper Cape Cod area was obtained from the U.S. Geological Survey. This data was utilized to give accurate terrain elevations of the receptor locations as well as the burn sites.

2.3.3 Modeling Input Parameters

The ISCST3 model input parameters that were used to simulate the open burning of propellant at Camp Edwards are shown in Table 2-12. Each gun and mortar point where bag burning took place was treated as a volume source. The following volume source inputs were determined using actual burn descriptions and recommendations in the ISC3 manual (USEPA, 1995): source height, initial horizontal dimension, and initial vertical dimension.[2]

Because the HHRA focused on chronic health risks, the model was configured to return annual averages of ambient concentration, dry deposition rate, and wet deposition rate for each receptor location. In addition, at each receptor location, the contributions from each gun point were added together to determine the total annual concentration and deposition rates from burning M1 propellant. Similarly, the contributions from each mortar point were added together to determine the total annual C/DRs from burning M9 propellant.

As seen in Table 2-12, the dispersion model was run using a unit emission rate of one gram/second. This approach allowed for more accurate results from the model which does not return enough significant digits when using very small emission rates (or burn rates).

[2] As of the printing of this draft report, a sensitivity analysis of these volume source input parameters has not been completed. The sensitivity analysis (including discussion on its impact on the health risk numbers) will be completed for the final report.

Table 2-12. ISCST3 Model Parameters for Each Gun or Mortar Point

Parameter	*Input*
Source Type	Volume
Source Height	1.0 meter
Initial Horizontal Dimension (σ_{YO})	1.0 meter
Initial Vertical Dimension (σ_{ZO})	2.0 meters
Plume Depletion Option	Wet and Dry
Terrain Option	Simple and Complex
Averaging Time	Annual
Urban/Rural Classification	Rural
Emission Rate (unit)	1 g/s

In addition to using a unit emission rate, the model was configured to calculate depositions and concentrations for a generic compound using the recommended scavenging coefficients found in Table 2-13. The modeling results based upon this generic compound released at a unit emission rate are called unit C/DRs. The appropriate unit C/DRs (Table 2-14) were multiplied by the array of chemical-specific emission rates (in Table 2-6) to obtain chemical-specific C/DRs.

Also, the model was run in both particulate mode and vapor mode to simulate different chemical phases emitted from the burning. Table 2-13 contains the USEPA-recommended particulate and vapor mode input parameters that were used to calculate both surface depositions and air concentrations.

Table 2-13. Particle and Scavenging Coefficient Input Parameters

ISCST3 Model Input Parameter	*Value*	*Units*
Particle Density	1.0	g/cm^3
Array of Particle Sizes	1.0, 6.0, 15.0	µm
Fraction of Emissions in Each Particle Class	0.78, 0.19, 0.03	Unitless
Particle Scavenging Coefficients for Liquid Precipitation	4.0E-05, 4.2E-04, 6.7E-04	hr/mm-s
Particle Scavenging Coefficients for Frozen Precipitation	1.3E-05, 1.4E-04, 2.2E-04	hr/mm-s
USEPA Liquid Vapor Scavenging Coefficient	1.7E-04	hr/mm-s
USEPA Frozen Vapor Scavenging Coefficient	5.7E-05	hr/mm-s

2.3.4 Unit Concentration and Deposition Rates

The generic, unit C/DRs determined from the ISCST3 model were averaged for all modeled years at each receptor location. This resulted in a long-term or chronic estimate of C/DRs at each receptor location. The unit C/DRs for both gun points and mortar points that were used to evaluate each of the population scenarios are presented in Tables 2-14 (a-f).

The maximum fenceline unit C/DRs (Table 2-14(a)) were used to evaluate the indirect risk (via deposition: P_{dd}, P_{wd}, V_{wd}) for both onsite and offsite residents and worker/students because the maximum fenceline deposition rate was higher than those at the onsite resident and

worker/student receptor locations. For the same reason, the maximum fenceline deposition rates were also used to calculate the contribution to risk of consuming vegetables from a home garden. The maximum fenceline inhalation concentrations (P_c and V_c), though, were used only for offsite residents and offsite workers. The maximum onsite resident, worker, and student unit C/DRs (Tables 2-14(b,c,d)) were used to calculate chemical-specific concentrations to determine the direct (or inhalation) risk for the onsite resident, worker, and student.

Table 2-14(a). Maximum Fenceline Unit C/DRs

Source	*C/DR Parameter*	*UTM (E)*	*UTM (N)*	*Annual Unit C/DR*
Gun Points	P_c (ug/m^3)	369400	4623080	8.316E+00
	P_{dd} (g/m^2)	369373	4622581	3.447E-01
	P_{wd} (g/m^2)	369397	4623054	3.182E-02
	V_c (ug/m^3)	369400	4623080	8.668E+00
	V_{wd} (g/m^2)	369397	4623054	9.417E-02
Mortar Points	P_c (ug/m^3)	374704	4621975	3.551E+00
	P_{dd} (g/m^2)	374704	4621975	1.834E-01
	P_{wd} (g/m^2)	372507	4615630	2.300E-02
	V_c (ug/m^3)	374704	4621975	3.836E+00
	V_{wd} (g/m^2)	372499	4615610	4.210E-02

Table 2-14(b). Maximum Onsite Resident Unit C/DRs

Source	*C/DR Parameter*	*UTM (E)*	*UTM (N)*	*Annual Unit C/DR*
Gun Points	P_c (ug/m^3)	369300	4613400	1.897E+00
	V_c (ug/m^3)	369300	4613400	2.092E+00
Mortar Points	P_c (ug/m^3)	368600	4614000	1.342E+00
	V_c (ug/m^3)	368400	4614000	1.530E+00

Table 2-14(c). Maximum Onsite Worker Unit C/DRs

Source	*C/DR Parameter*	*UTM (E)*	*UTM (N)*	*Annual Unit C/DR*
Gun Points	P_c (ug/m^3)	370200	4613300	2.130E+00
	V_c (ug/m^3)	370200	4613300	2.352E+00
Mortar Points	P_c (ug/m^3)	370000	4613300	1.126E+00
	V_c (ug/m^3)	370000	4613300	1.258E+00

Table 2-14(d). Maximum Onsite Student Unit C/DRs

Source	*C/DR Parameter*	*UTM (E)*	*UTM (N)*	*Annual Unit C/DR*
Gun Points	P_c (ug/m^3)	368840	4612520	1.349E+00
	V_c (ug/m^3)	368840	4612520	1.507E+00
Mortar Points	P_c (ug/m^3)	368840	4612520	9.043E-01
	V_c (ug/m^3)	368840	4612520	1.032E+00

Tables 2-14(e,f) contain the average waterbody and watershed unit C/DRs used to calculate the chemical-specific C/DRs in the specific pond and watershed area. These chemical-specific C/DRs were used then to calculate the water and fish concentrations that contribute to

the risk of swimming and fishing in the various lakes and ponds. The C/DRs are averages of the grid that covers the pond and the respective watershed area.

Table 2-14(e). Average Waterbody Unit C/DRs

Waterbody Scenario	P_c (ug/m^3)	P_{dd} (g/m^2)	P_{wd} (g/m^2)	V_c (ug/m^3)	V_{wd} (g/m^2)
Gun Points					
Shawme/Upper Shawme	1.008E+00	3.796E-02	8.592E-03	1.090E+00	1.532E-02
Snake/Weeks	2.136E+00	8.160E-02	1.392E-02	2.305E+00	2.876E-02
Ashumet/Johns	5.049E-01	1.018E-02	3.125E-03	6.248E-01	5.244E-03
Osborn/Edmunds	1.297E+00	4.623E-02	1.094E-02	1.451E+00	2.254E-02
Rod and Gun Ponds	1.262E+00	3.818E-02	9.219E-03	1.447E+00	1.866E-02
Wakeby/Mashpee	7.566E-01	2.044E-02	4.572E-03	8.370E-01	6.867E-03
Mortar Points					
Shawme/Upper Shawme	1.359E+00	6.997E-02	1.028E-02	1.472E+00	1.713E-02
Snake/Weeks	1.207E+00	4.812E-02	1.215E-02	1.288E+00	2.088E-02
Ashumet/Johns	3.030E-01	7.001E-03	2.407E-03	3.579E-01	3.620E-03
Osborn/Edmunds	8.237E-01	2.987E-02	1.129E-02	9.331E-01	1.990E-02
Rod and Gun Ponds	1.005E+00	2.901E-02	8.977E-03	1.132E+00	1.580E-02
Wakeby/Mashpee	4.748E-01	1.377E-02	3.936E-03	5.222E-01	5.380E-03

Table 2-14(f). Average Watershed Unit C/DRs

Watershed Scenario	P_c (ug/m^3)	P_{dd} (g/m^2)	P_{wd} (g/m^2)	V_c (ug/m^3)	V_{wd} (g/m^2)
Gun Points					
Shawme/Upper Shawme	3.242E+00	1.732E-01	1.441E-02	3.432E+00	3.209E-02
Snake/Weeks	2.911E+00	1.128E-01	1.422E-02	3.155E+00	3.044E-02
Ashumet/Johns	1.490E+00	4.403E-02	1.009E-02	1.662E+00	2.115E-02
Osborn/Edmunds	1.000E+00	2.759E-02	5.621E-03	1.102E+00	9.181E-03
Rod and Gun Ponds	1.908E+00	7.060E-02	9.049E-03	2.096E+00	1.950E-02
Wakeby/Mashpee	1.230E+00	3.771E-02	9.408E-03	1.375E+00	1.865E-02
Mortar Points					
Shawme/Upper Shawme	2.531E+00	1.177E-01	1.377E-02	2.723E+00	2.343E-02
Snake/Weeks	3.382E+00	1.534E-01	2.116E-02	3.623E+00	3.793E-02
Ashumet/Johns	1.348E+00	3.929E-02	1.203E-02	1.524E+00	2.146E-02
Osborn/Edmunds	5.870E-01	1.731E-02	4.455E-03	6.411E-01	6.533E-03
Rod and Gun Ponds	1.305E+00	6.529E-02	7.511E-03	1.414E+00	1.214E-02
Wakeby/Mashpee	9.443E-01	2.919E-02	1.032E-02	1.095E+00	1.669E-02

2.4 Vapor/Particulate Fractions

Because both vapor and particulate modeling were done to simulate different chemical phases emitted from the burning, a vapor/particulate (V/P) fraction had to be included in the calculation of C/DRs for each chemical. The V/P fractions that were used are listed in Table 2-6. The USEPA provided some V/P fractions for certain COCs which were incorporated into this

evaluation. If a chemical-specific V/P fraction was not provided, then the particulate percentage was estimated using the Junge equation presented in Equation 2-4 (USEPA 1993a).

Equation 2-4:

$$\Theta = \frac{c * S_T}{p + (c * S_T)}$$

where:

Θ	=	particulate percentage, unitless
c	=	constant developed by Junge, 1.7E-04 atm-cm
S_T	=	total surface area of atmospheric aerosols in relation to total volume of air, cm^2/cm^3
p	=	solute saturation vapor pressure, atm

2.5 Chemical-Specific Concentration and Deposition Rates

The chemical-specific C/DRs associated with burning M1 and M9 propellant were determined by combining the chemical-specific emission rates (Table 2-6) with the appropriate V/P fractions (Table 2-6) and the generic, unit C/DRs (Tables 2-14 (a-f)).
Equations 2-5(a) through 2-5(e) show the calculation for each chemical-specific C/DR.

Equations 2-5(a) – 2-5(e):

$$(a)\quad Pc\ (ug/m3) = Chemical\ Emission\ Rate\ (g/s) * (Particulate\ Fraction) * Unitized\ Pc\left(\frac{(ug/m3)}{(1\ g/s)}\right)$$

$$(b)\quad Vc\ (ug/m3) = Chemical\ Emission\ Rate\ (g/s) * (Vapor\ Fraction) * Unitized\ Vc\left(\frac{(ug/m3)}{(1\ g/s)}\right)$$

$$(c)\quad Pdd\ (g/m2) = Chemical\ Emission\ Rate\ (g/s) * (Particulate\ Fraction) * Unitized\ Pdd\left(\frac{(g/m2)}{(1\ g/s)}\right)$$

$$(d)\quad Pwd\ (g/m2) = Chemical\ Emission\ Rate\ (g/s) * (Particulate\ Fraction) * Unitized\ Pwd\left(\frac{(g/m2)}{(1\ g/s)}\right)$$

$$(e)\quad Vwd\ (g/m2) = Chemical\ Emission\ Rate\ (g/s) * (Vapor\ Fraction) * Unitized\ Vwd\left(\frac{(g/m2)}{(1\ g/s)}\right)$$

2.6 Modeling Data

Although the important and necessary results of the model runs are shown in Tables 2-14(a-f), the model output files are also available for review. Because of the large amount of data generated from the model runs, the data has been put on CD-ROMs and is available from the Joint Programs Office at MMR.

Section 3

HUMAN HEALTH RISK ASSESSMENT

3.0 Human Health Risk Assessment

3.1 Definition of Study Area

The study area chosen for this HHRA included areas within a 5-kilometer radius of the MMR, and those areas located on MMR.

3.2 Data Collection and Evaluation

For HHRAs, the site-specific data collection and evaluation component focused on collecting the following types of data:

* Hydrogeological
* Metetorological
* Site characteristics
* Operational
* Emissions
* Toxicological

The IG provides default values for many of the input parameters required to complete the HHRA, but extensive data evaluation is crucial for completion of the analysis. Generally, the default values recommended by the USEPA are conservative which ensures protection of the most sensitive elements of the population. All of the default values used in the HHRA can be found in Appendix B.

3.2.1 Selection of Waterbodies for the HHRA

Waterbodies around the MMR were located by topographical map and by an onsite visit by CHPPM personnel. Ten waterbodies were selected to be evaluated in the HHRA. The waterbodies were selected based on their locations, and on reports from MMR personnel that indicated where recreational activities were likely to occur. Lakes were chosen so that there were waterbodies from all sides of the installation, both on and off the installation, and where fishing and swimming activities were likely to occur. The waterbodies were grouped into five pairs of two; each pair was modeled as a single entity with one watershed area. Information on the waterbodies was obtained from topographical maps, and from Jacobs Engineering. In the HHRA, the ponds with the highest concentrations of the chemicals of concern (COC) were used to determine the fish and surface water concentrations for all scenarios. The following ponds and lakes were evaluated in the HHRA.

* Upper and Lower Shawnee. These ponds are located to the northeast of the installation, approximately 4 km from the northern edge of the MMR impact area, in the town of Sandwich.

* Mashpee and Wakeby Ponds. These connecting waterbodies are located to east of the installation.

* John's and Ashumet Ponds. These ponds are located to the south of the installation.

* Edmunds and Osborne Ponds. These ponds are located in the housing area of the MMR.

* Rod and Gun Club Ponds. These small ponds, used for fishing, are located on the northwest corner of the installation.

* Snake and Weeks Ponds. These ponds are located on the installation. Snakes Pond is approximately 2 km south of the impact area, while the smaller Weeks Pond is just southwest of Snakes Pond.

3.2.2 Site-Specific Data

After the air modeling was completed, the following site-specific data were needed to complete the HHRA:

* average annual precipitation (P)

* average annual irrigation (I)

* average annual surface water runoff (R)

* average annual evapotranspiration (Ev)

* surface areas of lakes and ponds (WA_w)

* average annual volumetric flow rates in the ponds and lakes (Vfx)

* depths of water columns in the ponds (dw)

* total watershed area (WAL)

* impervious watershed area (WAI); and,

* Universal Soil Loss Equation (USLE) rainfall factor (RF).

With the exception of the average annual irrigation (I), which used the USEPA default value, specific values were obtained for each of the other pieces of data. The waterbody-specific data is shown in Table 3-1. The other values can be found in Appendix B. Conservative assumptions were used. For instance, all the ponds were assumed to be quiescent, not flowing, which would lead to a higher concentration of the COCs. The Empirical Coefficients were determined from by interpolating from the values in Table 4.5.8 of the IG.

Table 3-1: Waterbody Data

Waterbody Name	Waterbody Area (m^2)	Average Depth (m)	Watershed Area (m^2)	Watershed Area-Impervious (m^2)	Vfx (m^3)	Empirical Coefficient
Ashumet/ Johns	2111580	9.14	21315608	12789365	1065784	1.8
Mashpee/ Wakeby	2897179	10.7	8814144	2203536	4407072	1.8
Upper/Lower Shawnee	181641.3	5	4595525	919105	2297763	1.8
Edmunds/ Osborne	59033.4	2	3401234	1020370	1700617	1.8
Snake and Weeks	351562	10	9828125	1965625	4914063	1.8
Rod and Gun Club	50781	2	3656250	365625	1828125	1.8

3.2.3 Selection of Chemicals of Concern

The COCs were taken from the list of compounds emitted from the bag burning process as described in Section 2.0. For the direct inhalation analysis, all compounds that were quantified in the DPG study (MAARNG, 1994) were retained as COCs. This is a conservative approach, as the COCs were not limited to those suggested in the IG. For the indirect analyses, all compounds detected were retained on the list of COCs except volatiles (which are not expected to remain in the environment), and calcium, potassium, and sodium (essential nutrients for which toxicological data and fate and transport data is not available), and a,a dimethylphenethylamine, 2-nitrodiphenylamine, and 2-nitropyrene, for which fate and transport and toxicity data were not available.

3.2.4 Identification of Potentially-Exposed Populations

The HHRA considered the following individual receptors:

* Adult onpost resident who works onpost, consumes vegetables from a home garden, and consumes fish caught recreationally

* Adult onpost resident who works offpost, consumes vegetables from a home garden, and consumes fish caught recreationally

* Adult offpost resident who works onpost, consumes vegetables from a home garden, and consumes fish caught recreationally

* Adult offpost resident who works offpost, consumes vegetables from a home garden, and consumes fish caught recreationally

* Child onpost resident who attends school onpost, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

* Child onpost resident who attends school offpost, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

* Child offpost resident who attends school onpost, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

* Child offpost resident who attends school offpost, consumes vegetables from a home garden, consumes fish caught recreationally, and swims in local waterbodies

3.2.5 Exposure Pathways

A substance may pose a health hazard only if a complete exposure pathway exists that links the COC to a human population or to an individual. A complete exposure pathway, as defined by Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (RAGS) consists of four essential elements:

* A source and mechanism of substance release

* A receiving or transport medium (air, ground water, surface water, sediment, or soil)

* A point of potential human contact with the substances ("exposure point")

* An "exposure route" such as eating and drinking (ingestion) or breathing (inhalation)

If one or more of the above elements is missing, the pathway is incomplete

and no risk exists. The potentially complete pathways that were investigated in this HHRA were inhalation and ingestion. The specific inhalation and ingestion routes are described below.

The dermal contact exposure route was not evaluated in this health risk assessment for two reasons; one, because normally the contribution to an individuals exposure through dermal contact is so much smaller than exposure by other pathways that it does not it does not normally noticeably increase the risk., and two, data on dermal absorption by the COCs is not usually available.

3.2.5.1 Direct Inhalation

Direct inhalation of emissions from the propellant bag burning was evaluated for chronic noncarcinogenic effects and carcinogenic effects for each of the individuals listed in Section 3.2.4.

3.2.5.2 Soil and Dust Ingestion

Individuals working or playing outdoors may have been exposed to emissions that were deposited on or permeated into the surface soil. Individuals may also have been exposed to indoor dust that had its origins outdoors. Children are particularly sensitive to soil exposure pathways as they spend significant periods of time outdoors. Incidental ingestion of soil was evaluated for the individuals listed in Section 3.2.4.

3.2.5.3 Surface Water Ingestion

Propellant bag burning emissions may enter bodies of water in the vicinity of MMR through direct deposition onto the waterbody or through runoff of impacted soil that enters the waterbody, as well as from erosion. An individual may have been exposed to potentially contaminated water during recreational swimming by accidental ingestion of water. This route of exposure was evaluated for all the children listed in Section 3.2.4., as they are both the most likely to swim in local waterbodies, and the most susceptible.

3.2.5.4 Food Chain

Propellant bag burning emissions may have entered the food chain from various sources. The COCs may enter plant tissues from air-to-plant transfer, through absorption from substances directly deposited on the leaves, and by root uptake. The constituents absorbed by these plants may, in turn, be consumed directly by local residents who maintain gardens for recreational purposes.

Propellant bag burning combustion products dissolved in the surface water and adsorbed to underwater sediments may have been assimilated in the tissues of fish in

local waterbodies. Eating fish from these waterbodies may have exposed individuals to additional risk.

Produce grown in home gardens, and fish caught by recreational fishers were considered for all the individuals described in Section 3.2.4.

3.3 Exposure Assessment

The exposure assessment involved defining the study area; identifying the exposed individuals, identifying how an individual may have contacted a substance (the exposure pathway); determining the concentration of each substance in air, soil, surface water, sediments, and produce; and estimating the amount of substance to which each individual was exposed (intake). Paragraphs 3.1 through 3.2 address four of these components (definition of the study area; selection of the COCs; identification of the exposed individuals; and identification of the exposure pathways). The following sections will address the remaining exposure assessment components.

Throughout this report the major equations used to determine media concentrations and to calculate risks are shown. Other calculations that are needed are not shown in the text, but are in Appendix B. The equations shown in the text are numbered to match their numbers in Appendix B; consequentially the equation numbers in the text are not sequential.

3.3.1 Estimation of Media Concentrations

Fate and transport models that simulate the dispersion of open burning emissions in the environment were used to estimate the exposure concentrations in air, soil, sediments, surface water, and garden vegetables. These models are based on USEPA's 1990 IED, the 1993 IEDA, the 1994 IG, the Errata, and the North Carolina Protocol. Fate and transport modeling depends on the specific characteristics of the COCs. The chemical/physical parameters of each of the COCs and the source of the data is given in Appendix D.

3.3.1.1 Estimation of Air Concentrations

Section 2.0 describes the methods used to develop air concentrations.

3.3.1.2 Estimation of Soil Concentrations

Soil concentrations are required to estimate the uptake of substances from the soil by vegetation, and to determine the amount of a chemical that may have been inadvertently ingested with soil, as well as to determine the concentration in surface waters due to erosion. Equation 1 was used to estimate the soil concentrations for the carcinogenic COCs, and Equation 2 was used to estimate the soil concentrations for noncarcinogens. The soil concentration for carcinogens time-averages the concentration

in the soil over the exposure period (Research Triangle Institute, 1997). The COC soil concentration averaged over the exposure duration is used for carcinogenic chemicals, where the risk is averaged over the lifetime of an individual. Because the hazard quotient associated with noncarcinogenic COCs is based on a reference dose rather than a lifetime exposure, the highest annual average COC soil concentration occurring during the exposure duration period was used for the noncarcinogenic COCs. The highest annual average COC soil concentration would occur at the end of the time period of combustion USEPA, 1994c; Research Triangle Institute, 1997).

The deposition term (Ds) is determined by the modeling, and takes into consideration both the wet and dry deposition of particles and vapors to soil.

For this HHRA, the following site-specific assumptions were made:

* Propellant bag burning has been occurring at MMR for 50 years.

* The assumed residency length is 30 years. This is the national upper-bound time (90th percentile) at one residence; the national median time (50th percentile) at one residence is 9 years (USEPA, 1989).

* The concentration in the soil over the last 30 years of the burning was higher than in any other 30-year period of the burning, due to the continued accrual of propellant bag emissions.

* The concentration in the environment was highest immediately prior to ceasing the burning, due to the accrual of the propellant bag emissions over the 50-year period of burning.

Equation 1: Soil Concentration for Carcinogens

$$Sc = \left[\frac{Ds}{ks * (T_c - T_1)}\right] * \frac{[T_c + \exp(-ks * T_c)]}{ks} - T_1 + \left[\frac{\exp(-ks * T_1)}{ks}\right]$$

Equation 2: Soil Concentration for Noncarcinogens

$$Sc_{Tc} = \frac{Ds * [1 - \exp(-ks * {}_{Tc})]}{ks}$$

where:

$$Ds = \frac{100\ [(0.31536 * Vdv * Vc + Vwd) + (Pwd + Pdd)]}{Z * BD}$$

Sc = Average soil concentration over exposure duration (mg/kg)
Sc_{Tc} = Soil concentration at a time Tc (mg/kg)
Ds = Deposition term (mg/kg-yr)
T_c = Time period over which deposition occurs (time period of combustion)
ks = COC soil lost constant (yr-1)
T_1 = Time period at the beginning of combustion (yr)
T_2 = Length of exposure duration (yr)
Z = Soil mixing depth (cm)
BD = Soil bulk density (g/cm3)
0.31536 = Unit conversion factor (mg-g-s/cm-ug-yr)
V_{dv} = Dry deposition velocity (cm/s)
V_c = Yearly vapor phase air concentration for the COC (g/m^2-yr)
100 = Units conversion factor ([mg-m2]/[kg-cm2])
V_{wd} = Yearly wet deposition from vapor phase for the COC (g/m^2-yr)
P_{wd} = Yearly wet deposition from particle phase for the COC (g/m^2-yr)
P_{dd} = Yearly dry deposition from particle phase for the COC (g/m^2-yr)

The variables used in Equations 1-3 are in Appendix B. In calculating the soil concentrations, the loss of the chemical from the soil due to the processes of leaching, surface runoff, degradation, and volatilization are also considered. Appendix B includes the equations for these calculations.

3.3.1.3 Estimation of Vegetable Concentrations

The concentrations of substances in vegetation is required to estimate the human exposure through ingestion of vegetables grown in a home garden. In the HHRA, the concentrations of the COCs were estimated for aboveground vegetables and root vegetables.

Uptake of constituents from the air into aboveground plants can occur through several mechanisms including direct deposition of COCs onto the plant, direct uptake of vapor phase COCs, and root uptake of COCs deposited on the soil. For his analysis root uptake is omitted for aboveground vegetation. Root uptake is typically a much less important mechanism than direct deposition to the aerial parts of plants (USEPA, 1994b). Direct uptake of vapor phase COCs are included, as this can be significant for some COCs. Direct deposition of particle phase COCs on the plant was calculated at the location of maximum combined (wet and dry) deposition. Direct uptake of vapor phase COCs was calculated at the location of maximum air concentration. Root vegetables may contain COCs due to root uptake of COCs deposited on the soil. Direct deposition and vapor phase uptake are not important for root vegetables, as none of the edible portion is above the ground (USEPA, 1994b). The necessary equations are shown below. The variable values are found in Appendix B.

Equation 8: Aboveground Vegetable Concentration Due to Direct Deposition

$$Pd = \frac{1000 * [P_{dd} + (Fw * P_{wd})] * Rp * [1.0 - \exp(-kp * Tp)}{Yp * kp}$$

where:
Pd = Concentration in plant due to direct deposition (mg/kg)
1000 = Units conversion factor (mg/g)
P_{dd} = Yearly dry deposition from particle phase for the COC, g/m^2-yr
P_{wd} = Yearly wet deposition from particle phase for the COC, g/m^2-yr
Fw = Fraction of wet deposition that adheres to plant (dimensionless)
Rp = Interception fraction of edible portion of plant (dimensionless)
kp = Plant surface loss coefficient (yr-1)
Tp = Length of plant exposure to deposition of edible portion of plant, per harvest (yr)
Yp = Yield or standing crop biomass of the edible portion of the plant (kg DW/m2)

Equation 9: Aboveground Vegetable Concentration Due to Air-to-Plant Transfer

$$Pv = \frac{V_c * Bv * VG_{ab}}{P_a}$$

where:
Pv = Concentration of COC in the plant due to air-to-plant transfer (mg/kg)
V_c = Yearly vapor phase air concentration for the COC, *u*g/m^2
Bv = Air-to-plant biotransfer factor ([mg/COC/kg plant tissue DW]/[ug COC/g air])
VG_{ab} = Empirical correction factor for aboveground vegetables (unitless)
P_a = Density of air

Equation 10: Aboveground Produce Concentration Due to Root Uptake

$$Pr_{ag} = Sc * Br$$

where:
Pr_{ag} = Concentration of COC in aboveground plants due to direct uptake from soil (mg/kg)
Sc = Average soil concentration of COC over exposure duration (mg/kg)
Br = Plant-soil bioconcentration factor for aboveground produce [ug/g DW]/[ug/g soil]

Equation 11: Root Vegetation Concentration Due to Root Uptake

$$PR_{bg} = \frac{Sc * VG_{bg} * RCF}{Kd_s}$$

where:
PR_{bg} = Concentration of COC belowground plant parts due to root uptake (mg/kg)
Sc = Soil concentration of COC (mg/kg)
VG_{bg} = Empirical correction factor for belowground vegetables (unitless)
Kd_s = Soil-water partition coefficient (mL/g)
RCF = Ratio of concentration in roots to concentration in soil pore water ([mg COC/kg plant tissue FW]/[ug COC/mL pore water])

3.3.1.4 Estimation of Surface Water and Sediment Concentrations

The concentration of the COCs in surface water is required to estimate exposure through surface water ingestion while swimming, and to estimate the uptake of substances from the surface water by fish. To determine surface water and sediment concentrations, the load to the surface waterbody from various sources must be estimated. These sources include the loads from soil erosion, surface runoff, direct deposition, from diffusion from the air. The amount of the COCs in the water and bound to sediment in the water was determined using information on the specific waterbodies (see Table 3-1). The equations used, and the variable explanations, are in Appendix B. The following site-specific information was used in this HHRA:

* Surface area runoff was determined to be 25 centimeters (cm) per year, based on the Water Atlas of the United States (1973) value for surface water runoff (which is defined as all flow contributions to surface waterbodies, including direct runoff, shallow interflow, and ground-water recharge) of 50 cm per year, divided by 50%, to remove the effect of non-surface runoff contributions (USEPA, 1994c). Although Jacobs Engineering (Tingley, 1998) determined surface water runoff to these kettle hole ponds to be negligible due to the highly pervious sands, to take into account very extreme situations and to err on the side of protecting human health, a runoff of 25 cm per year was assumed.

* The volumetric flow for each of the ponds was determined by multiplying the watershed area by the amount of flow contributions to surface waterbodies (including direct runoff, shallow interflow, and ground water recharge) per year (USEPA, 1994c). This value was determined from the Water Atlas of the United States to be 50 cm per year (Geraghty, 1973).

3.3.1.5 Estimation of Fish Concentrations

Emissions from propellant bag burning may enter local surface waterbodies through several means, as discussed above. These emissions may be incorporated into fish living in the waterbody. The concentration of constituents in fish is required to estimate human exposure via ingestion. The 1990 IED and the 1993 IEDA discuss several

methods for determining concentrations of substances in fish. The method most appropriate for each COC was used.

* For certain lipophilic compounds, bioaccumulation factors (BAFs) were used to obtain lipid-based fish concentrations. The BAF multiplied by the total water column concentration gives a lipid-based fish tissue concentration.

* For other substances, the bioconcentration factor (BCF) was determined from the scientific literature, or calculated using the K_{ow}. The concentrations of COC in fish were calculated as shown in Equations 12 and 13. All other equations used, along with the parameters and variables are in Appendix B.

Equation 12: Fish Concentration from Dissolved Water Concentration

$$C_{fish} = C_{dw} * BCF$$

or

Equation 13: Fish Concentration from Total Water Column Concentration

$$C_{fish} = C_{wt} * BAF$$

where:
C_{fish} = Fish concentration (mg/kg)
C_{dw} = Dissolved water concentration (mg/L)
C_{wt} = Total water column concentration (mg/L)
BCF = Bioconcentration factor (L/kg)
BAF = Bioaccumulation factor (L/kg)

3.3.2 Estimating Exposures and Intakes in Exposed Populations

To quantitatively assess the potential exposures associated with the direct (inhalation) and indirect (ingestion) exposure routes, daily intakes were determined. Appendix B presents the equations that were used to provide estimations of the daily intakes.

3.3.2.1 Inhalation of Air

This exposure pathway involves the inhalation of volatile substances from the air or the inhalation of suspended particulates in the air that are substance-bearing. For assessment of cancer risk, an inhalation intake rate was developed. Equation 47 was used to develop the inhalation intake for the cancer assessment. The variable values are given in Appendix B. For the chronic noncancer assessment, the respirable concentration in the air as modeled was used to calculate the hazard. Therefore, inhalation intake for chronic

noncancer is not calculated; instead a hazard quotient (HQ) is calculated. The formula for calculating the HQ is shown below.

Equation 47: Inhalation Intake for Carcinogenic Risk Assessment

$$ADI_{inh} = \frac{C_{air} * IR * ET * EF * ED * 0.001}{BW * AT}$$

where:
ADI_{inh} = Average daily intake via inhalation (mg/kg-day)
C_{air} = Respirable concentration of substance in air (mg/m^3)
IR = Inhalation rate, (m^3/hr)
ET = Exposure time (hr/day)
EF = Exposure frequency (days/yr)
ED = Exposure duration (yr)
BW = body weight (kg)
AT = averaging time (days)
0.001 = Units conversion factor

The values used in this equation are shown for both adult and child in Appendix B.

Equation 49: Hazard Quotient Calculation for Noncarcinogens

$$HQ_{(inh)} = \frac{C_{air} * 0.001}{RfC}$$

where:
$HQ_{(inh)}$ = Hazard quotient via inhalation (unitless)
C_{air} = Respirable concentration in air (ug/m^3)
RfC = Reference concentration (mg/m^3)
10^{-3} = Units conversion factor (mg/ug)

3.3.2.3 Soil Ingestion

This exposure route requires direct contact with soil upon which emissions from the propellant bag burning have been deposited. The contact may be via the hands or lips, followed by inadvertent hand-to-mouth contact or licking of lips. The soil intake is presented below. Equations for calculating the COC concentrations in soil are given in Section 3.5.1.2. The variable values are given in Appendix B.

Equation 35: Soil Ingestion Intake:

$$I_{soil} = Sc * Cr_{soil} * F_{soil}$$

where:
I_{soil} = Daily intake of COC from soil (mg/day)
Sc = Soil concentration (mg/kg)
Cr_{soil} = Consumption rate of soil (kg/day)
F_{soil} = Fraction of consumed soil contaminated (unitless)

3.3.2.4 Ingestion of Vegetables from Home Garden

An intake was estimated for aboveground vegetation and for root vegetation. Equations for calculating the concentrations of COCs in aboveground and belowground vegetables is found in Section 3.3.1.3. The ingestion intake equations for plants grown in home gardens are below. The variable values are found in Appendix B.

Equation 36: Aboveground Vegetable Intake

$$I_{ag} = (Pd + Pv + Pr) * Cr_{ag} * F_{ag}$$

Equation 37: Belowground Vegetable Intake

$$I_{bg} = Pr_{bg} * CR_{bg} * F_{bg}$$

where:
I_{ag} = Daily intake of COC from aboveground vegetables (mg/day)
Pd = Concentration in aboveground vegetables due to deposition (mg/kg)
Pv = Concentration in aboveground vegetables due to air-to-plant transfer (mg/kg)
Pr = Concentration of COC in the plant resulting from direct uptake from soil (mg/kg)
CR_{ag} = Consumption rate of aboveground vegetables (kg/day)
F_{ag} = Fraction of aboveground vegetables contaminated (unitless)
I_{bg} = Daily intake of COC from root vegetables (mg/kg)
Pr_{bg} = Concentration in root vegetables (mg/kg)
CR_{bg} = Consumption rate of root vegetables (kg/day)
F_{bg} = Fraction of root vegetables contaminated (unitless)

3.3.2.5 Ingestion of Locally-Caught Fish

This exposure route requires consumption of locally-caught fish that have been exposed to propellant bag burning emissions deposited in lakes and ponds. The intake equation is presented below. The variable values are given in Appendix B.

Equation 38: Fish Ingestion Intake

$$I_{fish} = C_{fish} * Cr_{fish} * F_{fish}$$

where:
I_{fish} = Daily intake of COC from fish (mg/day)

C_{fish} = Fish concentration (mg/kg)
Cr_{fish} = Consumption rate of fish (kg/day)
F_{fish} = Fraction of fish contaminated (unitless)

3.3.2.6. Incidental Ingestion of Water While Swimming

This exposure route requires incidental ingestion of surface water into which propellant bag burning emissions have been deposited. Ingestion may occur during swimming or other recreational water activities. The intake equation is presented below. For this HHRA, the following assumptions were made:

* The individual swims 30 days a year in area ponds. The highest calculated concentration of each COC has been assumed for all of the studied ponds. The USEPA recommended value is once per month, or 12 times per year (USEPA, 1997).

* Four hours are spent in the water each time a person goes swimming in an outdoor pond. The 90^{th} percentile value is 3 hours (USEPA, 1997). Variable values can be found in Appendix B.

* 50 milliliters of water are swallowed every hour while swimming. This is the USEPA default value (EPA, 1989).

Equation 39: Incidental Surface Water Ingestion

$$I_{sw} = \frac{C_{wtot} * CR * ET * EF}{365}$$

where:
I_{sw} = Daily intake of COC from surface water while swimming (mg/day)
C_{wtot} = Total water column concentration (mg/L)
CR = Contact Rate (L/hr)
ET = Exposure Time (hours/event)
EF = Exposure Frequency (events/yr)
365 = Averaging Time (dy)

When using the site-specific values mentioned above, this equation simplifies to

$$I_{sw} = C_{wtot} * 0.016 \text{ L/dy}$$

3.3.2.7. Total Daily Intake of Compounds

The total amount of a COC that is ingested is calculated by adding the amount ingested from above and below ground vegetables, fish, soil, and surface water as shown below.

Equation 40: Total Ingestion Intake

$$I = I_{soil} + I_{ag} + I_{bg} + I_{fish} + I_{sw}$$

where:
I = Total daily intake of COC (mg/day)
I_{soil} = Daily intake of COC from soil (mg/day)
I_{ag} = Daily intake of COC from aboveground vegetables (mg/day)
I_{bg} = Daily intake of COC from root vegetables (mg/day)
I_{fish} = Daily intake of COC from fish (mg/day)
I_{sw} = Daily intake of COC from surface water ingested while swimming

3.4 Toxicity Assessment

Hazard identification and dose-response evaluations are two major components of the toxicity evaluation phase of the HHRA.

3.4.1 Hazard Identification

In hazard identification, an attempt is made to identify the type of toxic effect produced by a substance and the exposure conditions associated with that effect. All substances are toxic at some dose and exposure duration. In the HHRA, the toxicity of each COC was evaluated for the inhalation and ingestion routes of exposure where data were available.

A number of the COCs have been identified as possible, probable, or known human carcinogens. Carcinogenic effects were assessed separately from other chronic systemic effects.

3.4.2 Dose-Response Evaluation

Dose-response evaluation is the process of characterizing and quantifying the degree of toxic effects in terms of the exposure doses. The numerical expression of chronic and subchronic dose-response information is typically the Cancer Slope Risk Factor (CSF) or Unit Risk (UR) for carcinogenic effects and the Reference Dose (RfD) or Reference Concentration (RfC) for chronic, systemic, or noncarcinogenic effects. The RfD is used for oral exposures, and the RfC applies to lung or systemic hazards from inhalation exposures.

3.4.2.1 Slope Factors and Unit Risks

The CSFs are determined by estimating the slope of the dose-response function for each COC. When sufficient human data are available, the value that best estimates the slope is used. When risk estimates are based on data from experimental animals, the toxicity value generated is an estimate of the 95th percentile upper confidence limit on the slope. In other words, the CSF is a plausible upper-bound estimate of the probability of

developing cancer as a result of exposure to a unit concentration of a particular carcinogen over a lifetime (USEPA, 1989).

Toxicity values for carcinogenic effects can also be expressed in terms of risk per unit concentration of the substance in the medium where human contact occurs. These measures, called URs, are calculated by dividing the slope factor by 70 kg (the default adult body weight) and multiplying by the inhalation rate (20 m^3/day) for risk associated with unit concentration in air. The standardized duration for unit risks is understood to be a continuous lifetime exposure. In the event the toxicity value of a COC is provided as a unit risk, the unit risk was used to derive the CSF. The following COCs are known or believed to be carcinogens: cadmium, lead, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, butyl benzyl phthalate, N-nitrosodiphenylamine, RDX, 2,4,6-trinitrotoluene, benzene, carbon tetrachloride, bis(2-ethylhexyl)phthalate, di-n-octyl phthalate, and 2,4-dinitrotoluene. Neither CSFs nor URs were available for lead or butyl benzyl phthalate.

3.4.2.2 Reference Doses (RfDs) and Reference Concentrations (RfCs)

Estimates of noncarcinogenic toxicity are based on the assumption that toxic effects will only occur after exposure exceeds some threshold level. The values derived are called RfDs or RfCs. There are two types of RfDs and RfCs: chronic and subchronic. The chronic RfD (or RfC) represents an estimate of a daily exposure level for humans, including sensitive individuals, that is unlikely to cause an adverse health effect, even if exposed for an entire lifetime. Chronic RfDs are specifically developed to be protective for exposures to a substance from 7 years to a lifetime (USEPA, 1989). Subchronic RfDs (or RfCs) represent an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects for exposures from 14 days to 7 years (USEPA, 1989).

The RfD and RfC values are estimated by dividing either the highest dose of the substance that did not produce a toxic effect in experimental studies [No Observed Adverse Effect Level (NOAEL)], or the lowest dose that did produce an adverse health effect [Lowest Observed Adverse Effect Level (LOAEL)] by the product of Uncertainty Factors (UFs) and a Modifying Factor (MF). The UFs account for:

* variation in general population

* extrapolation from animal data to humans

* extrapolation from a subchronic study to derive a chronic RfD (or RfC)

* use of an LOAEL when an NOAEL is not available

*situations when the available data do not adequately address all possible adverse outcomes in humans

The MF indicates the confidence in the quality of the data for predicting human health effects. The RfCs or RfDs were not available for the following COCs: acenaphthylene, 4-aminobiphenyl, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzonitrile, N-nitrosodiphenylamine, phenacetin, phenanthrene, and lead. Although not evaluated for systemic effects, several of these chemicals are known or believed to be carcinogens, and consequently were considered in the carcinogenic risk portion of the HHRA.

3.5 Toxicity Data Sources

In the HHRA, the relevant toxicity values were taken from the latest update of the USEPA Integrated Risk Information System (IRIS). Verified toxicity values were not always available. Other reliable sources, such as Health Effects Assessment Summary Tables (HEAST) were used to compile toxicity data for some of the COCs. In addition, the USEPA Environmental Criteria and Assessment Office (ECAO) and Superfund Health Risk Technical Support Center (TSC) were consulted. The Risk-Based Concentrations Table from EPA Region III was used in the absence of other data. The toxicity value and the source of the value are shown in Appendix E.

In this HHRA, where IRIS data were not available, the ambient air values from the Risk Based Concentration Table, developed by EPA Region III (USEPA, 1997b) were used; this is a conservative approach, as it assumes exposure to the COC by an inhalation route, even when, in reality, there may be no reasonable risk of exposure by that route. The ambient air number was converted to a Reference Dose-Inhalation (RFDi) by back calculating from the methadology shown in the table; the ambient air risk based concentration was divided by 3650, which was determined by the following term:

$$\frac{THQ * BW * ATn * 1000\ ug/mg}{EFr * ED_{tot} * IRa}$$

where:
THQ = Target Hazard Quotient = 1.0
BW = Body Weight = 70kg
ATn = Averaging Time = 30 yrs * 365 days
1000ug/mg = Units Conversion factor
EFr = Exposure Frequency = 350 days/yr
ED_{tot} = Exposure Duration Total = 30 years
IRa = Inhalation Rate Adult = 20 m^3/day

The RFDi (mg/kg/day) was then converted to an RfC using the following equation:

$$RfC\ (mg/m^3) = RfDi(mg/kg/day) * 70kg * 1000ug/mg * 1/20m^3$$

3.6 Substances Requiring Special Handling

Several of the COCs require a different toxicity assessment than the methodology outlined previously. Some of these substances have known toxic effects, but limited or no toxicity values. In other cases, the substances may speciate in the environment into forms which are considered more toxic. The substances requiring a special toxicity assessment in this HHRA are: lead, mercury, acid gases, and particulate matter.

3.6.1 Lead

The USEPA currently does not list any toxicity data for lead, even though it is classified as a B2 (probable) carcinogen, and it has known noncarcinogenic effects. Therefore the IG suggests a direct comparison of lead concentrations with media specific health-based levels. Lead concentrations in the soil and air were compared to the recommended levels of 100 mg/kg and 0.2 ug/m^3, respectively (USEPA 1994a).

In addition, the USEPA has developed an uptake/biokinetic modeling approach for evaluating the risks posed by exposures to lead. The Integrated Exposure Uptake Biokinetic Model (IEUBK) predicts potential blood lead levels for children from 0 to 7 years (USEPA, 1994c). Children are generally more susceptible to lead exposures than adults due to higher soil ingestion rates, greater absorption from the gut, and more critical toxic effects. The model was developed for children and their uptake and absorption rates; therefore it is not suitable for predicting lead levels in adults. The modeled results for children were compared to a default level of concern of 10 ug/dL. Results are shown in Section 4.3.

3.6.2 Mercury

Mercury can exist in either organic or inorganic forms in the environment. Methyl mercury is the most important form of mercury in terms of toxicity and health effects from environmental exposures. Mercury emissions from open burning are expected to be in an inorganic form. It is possible, however, that the mercury was converted to its more toxic organic form by biotransformation in the environment. The extent of such conversion was impossible to determine, so all mercury that was ingested was assumed to be methyl mercury, and the toxicity data for methyl mercury was used. Mercury that was inhaled would most likely be inorganic or elemental mercury, so the toxicity data for elemental mercury was used for inhalation.

3.6.3 Hydrochloric Acid and Particulate Matter

Major health effects resulting from HCl exposure are typically associated with the direct inhalation pathway. Toxicological data for assessing exposure to hydrochloric acid are available only for the health hazards associated with direct inhalation. Hydrochloric acid was assessed in the HHRA in the same way as all other COCs that are inhaled in the

noncarcinogenic health effects section. The possible health effects of hydrochloric acid are included in the calculation of the direct exposure hazard index.

The USEPA currently has limited toxicity data available for acid gases or respirable particulates [generally assumed to be particulates with an aerodynamic diameter equal to or less then 10 micrometers (PM_{10})]. These substances may affect the lungs, especially in susceptible individuals such as asthmatics, children, the elderly, and people with lung diseases. In this HHRA, particulate matter was compared to the National Ambient Air Quality Standard (NAAQS) of 50 ug/m^3 (40 CFR Part 50). This value is an annual arithmetic mean for particulate matter that is equal to or less than 10 microns in diameter (PM_{10}). Section 4.4 shows the results.

3.7 Risk Characterization

Characterization of risk is the final step of the assessment. In this step, for each exposure scenario the health effects criteria or benchmarks are used in conjunction with intake estimates which are calculated for each exposure pathway to arrive at the risk assessment endpoints. The assessment endpoints of the analysis were as follows: the increased probability of cancer in an individual over a lifetime, referred to as the excess lifetime cancer risk (or simply, individual cancer risk) arising from both oral and inhalation routes of exposure; for oral exposures, a measure of an individual's exposure to chemicals with noncarcinogenic health effects relative to the RfD, referred to as the hazard quotient; and for inhalation exposures, an HQ relative to the RfC. Population risk is not an assessment endpoint for this analysis. Although oral and inhalation routes of exposure were handled separately in the analysis, the individual risks associated with exposures to carcinogenic chemicals were combined for the oral and inhalation routes of exposure to give a total risk.

3.7.1 Estimation of Carcinogenic Risks

Risk estimates for carcinogenic compounds are generally expressed as an excess upper-bound probability (e.g., 1×10^{-5}) that an individual in a population will develop cancer as a result of exposure to the substance. These risks are termed excess lifetime cancer risks (ELCR). An ELCR of 1×10^{-5} indicates that an individual has a chance of developing cancer from exposure to the carcinogenic substance somewhere in the range from zero to 1 in 100,000. The USEPA states that to ensure the protection of human health, the total incremental risk from the high-end individual exposure to carcinogenic constituents should not exceed 1 in 100,000 (USEPA, 1994b); consequently a risk of 1×10^{-5} or less was considered low enough to not be of a public health concern in this HHRA.

In this HHRA there was the potential for exposure to multiple substances. The cancer risks for each individual constituent were summed to obtain an exposure pathway total. In addition, the risk estimates were summed across exposure pathways, but only for

those exposure pathways to which the individual was subjected. The following equation was used to estimate cancer risk:

Equation 41: For Indirect Cancer Risk

$$\text{Indirect Cancer Risk} = \frac{I_{tot} * ED * EF * CSF}{BW * AT * 365}$$

where:
I_{tot} = Total Daily Intake of COC (mg/day)
ED = Exposure Duration (yr)
EF = Exposure Frequency (days/yr)
CSF= Cancer Slope Factor
BW = Body weight
AT= Averaging Time
365 = Unit conversion factor, day to year

Equation 46: For Inhalation Cancer Risks:

$$\text{Inhalation Cancer Risk} = ADI_{inh} * CSF$$

where:
Inhalation Cancer Risk = The excess lifetime probability of developing cancer due to exposure to open burning emissions of the COC (unitless)
ADI^{inh} = Average daily intake via inhalation of the COC (mg/kg/day)
CSF = Carcinogenic slope factor for the COC (mg/kg/day)

3.7.2 Estimation of Chronic Noncarcinogenic Hazards

Unlike estimate for a carcinogen's effect, to estimate the noncarcinogenic hazard, it is presumed that there is a threshold for effect. That is, the HQ assumes that there is a level of exposure below which it is unlikely for even sensitive individuals to experience an adverse health effects. If the exposure exceeds this threshold, there may be concern for potential noncancer effects (USEPA, 1989). The equations used to determine the noncarcinogenic hazards [hazard quotients (HQ)] are as follows:

Equation 47: For Noncancer Inhalation Exposures:

$$HQ_{inh} = \frac{C_{air} * 0.001}{RfC}$$

where:
HQ_{inh} = Inhalation hazard quotient for the COC (unitless)
C_{air} = Respirable concentration of the COC in air (mg/m^3)

RfC = Reference concentration (mg/m^3)
0.001 = Unit conversion factor

Equation 42: For Noncancer Oral Exposures:

$$HQ = \frac{I_{tot}}{BW \times RfD}$$

where:
HQ = Hazard quotient for the COC (unitless)
I_{tot} = Total daily intake of the COC (mg/day)
RfD = Reference dose for the COC (mg/kg/day)
BW = Body weight (kg)

Chronic RfDs are used with exposures lasting greater than 7 years. Some of the exposure scenarios, however, may model exposures for less than this time, e.g., the child scenarios. Subchronic RfDs and RfCs are preferable for these exposures and were used if available. If subchronic RfDs and RfCs were not available, the more conservative chronic value were used.

The HQ values for each substance associated with a given exposure pathway were summed. This summation is referred to as the hazard index (HI). Derivation of an HI by summing all substances for a given exposure pathway is not entirely appropriate, because different substances have different effects and mechanisms of action on a target organ or system. In addition, the cumulative effects of substances may be antagonistic or synergistic.

The calculation of HI values should take into account background exposures not associated with propellant bag burning emissions. To account for background exposures the emissions may only contribute 25% of the noncarcinogenic health standard, which in most cases is one (or unity) (USEPA, 1994b). Consequently, in this HHRA an HI of 0.25 or less was considered below the threshold of concern.

Section 4

HUMAN HEALTH RISK ASSESSMENT RESULTS

4.0 Human Health Risk Assessment Results

4.1 Excess Lifetime Cancer Risks Summary.

For both children and adults, the ELCRs were less than the 1 in 100,000 considered acceptable by the USEPA. The individual with the highest risk for adults was one who both lives and works offsite. All adults were assumed to have identical exposures to soil, fish, water ingested by swimming, and garden vegetables. The concentration of each of these was calculated at the site of maximum concentration for the COCs; consequently the indirect risk was the same for all the adult scenarios. Table 4-1 shows the excess lifetime cancer risks for each scenario.

Table 4-1: Adult Cancer Risk

Scenario	Indirect Cancer Risk	Direct Cancer Risk	Total Cancer Risk
Offsite Resident/ Offsite Worker	4×10^{-10}	2×10^{-10}	6×10^{-10}
Offsite Resident/ Onsite Worker	4×10^{-10}	2×10^{-10}	6×10^{-10}
Onsite Resident/ Offsite Worker	4×10^{-10}	9×10^{-11}	5×10^{-10}
Onsite Resident/ Onsite Worker	4×10^{-10}	5×10^{-11}	5×10^{-10}

The same procedure was followed for the children's scenarios. The highest cancer risk for children is for the child who both lives and attends school off the installation. The bulk of the overall total cancer risk was through the indirect route. The ELCRs for each scenario are shown in Table 4-2.

Table 4-2: Child Cancer Risk

Scenario	Indirect Cancer Risk	Direct Cancer Risk	Total Cancer Risk
Offsite Resident/ Offsite Student	1×10^{-10}	5×10^{-11}	2×10^{-10}
Offsite Resident/ Onsite Student	1×10^{-10}	4×10^{-11}	2×10^{-10}
Onsite Resident/ Offsite Student	1×10^{-10}	2×10^{-11}	1×10^{-10}
Onsite Resident/ Onsite Student	1×10^{-10}	1×10^{-11}	1×10^{-10}

4.2 Noncancer Chronic Health Effects

The long-term noncancer effects are characterized by calculating an HI. The HIs for each scenario are shown in Table 4-3. The benchmark for an exposure considered safe is typically 1.0. However, to take into account the effects of background exposures, for this HHRA, the benchmark was set at 0.25. All scenarios, both adult and child, were less than the 0.25 benchmark, so it is unlikely that propellant bag burning would cause an adverse health effect.. The HI for each of the scenarios are found below. The majority of the noncancer risk was from the indirect pathways. The HIs for children are shown in Table 4-4.

Table 4-3: Adult Hazard Indices

Scenario	Indirect HI	Direct HI	Total HI
Offsite Resident/ Offsite Worker	0.00006	0.0001	0.0002
Offsite Resident/ Onsite Worker	0.00006	0.00009	0.0002
Onsite Resident/ Offsite Worker	0.00006	0.00005	0.0001
Onsite Resident/ Onsite Worker	0.00006	0.00003	0.00009

Table 4-4: Child Hazard Indices

Scenario	Indirect HI	Direct HI	Total HI
Offsite Resident/ Offsite Student	0.00007	0.0001	0.0002
Offsite Resident/ Onsite Student	0.00007	0.00009	0.0002
Onsite Resident/ Offsite Student	0.00007	0.00005	0.0001
Onsite Resident/ Onsite Student	0.00007	0.00003	0.0001

4.3 HHRA Lead Evaluation Summary

This HHRA evaluated lead in several ways. The predicted respirable lead concentrations and soil concentrations were well below the accepted regulatory standards. The respirable concentration of lead at the fenceline (the site of maximum concentration) was 2.55×10^{-6} ug/m^3. The health standard for lead in air is 0.2 ug/m^3. The maximum soil lead concentration contributed by propellant bag burning was estimated at 3.8×10^{-4} mg/kg. This is well below the acceptable level of 100 mg/kg. In running the IUEBK model, the predicted concentrations of lead in soil, vegetables, fish, and surface water

were too small to be input into the model (which had limited decimal places). The model was run with all default parameters applicable to the nation as a whole. The blood lead level was below 5.0 ug/dL for all ages from 0 to 7 years. The blood lead levels are probably less than 5.0 ug/dL since the air lead level value that was used was for an urban environment. The acceptable blood lead level is 10 ug/dL or less.

4.4 Particulate Matter

The respirable particulate concentration at the fenceline, which was the highest concentration, was estimated to be 5.93×10^{-3} ug/m^3, which is well below the NAAQS PM_{10} standard of 50 ug/m^3. Even if it assumed that 100% of the particulate matter is less than or equal to 2.5 microns, the amount of particulates emitted during propellant bag burning is less than the $PM_{2.5}$ standard of 15 ug/m^3.

4.5 Essential Nutrients

This risk assessment included several metals that were detected during the testing at the Bang-Box facility that are not believed to have adverse effects on human health at the levels in which they are present; in fact, they are essential nutrients for human health. These include potassium, sodium, and calcium. There was no toxicity or fate and transport data available for these metals. These metals, as well as aluminum and copper, were modeled using the Kd values for cadmium. The ingestion amounts were compared against the Recommended Daily Allowances (RDA) or the Minimum Requirements of Healthy Persons. The intakes shown are only from the indirect risk (ingestion). The amount inhaled was not compared to the RDA or Minimum Requirements of Healthy Persons. The results are shown below (Pennington, 1994). Zinc and copper are also compared against the RDAs, although they have toxicity data as well, and therefore are also included in the quantitative portion of the HHRA.

Table 4-5: Comparison of Intake from Propellant Bag Burning and Recommended Daily Allowance/Minimum Requirements of Healthy Persons of Essential Metals

Metal	Intake from Propellant Bag Burning (mg/day)	Recommended Daily Allowance/ Minimum Requirements of Healthy Persons (Adults)	Recommended Daily Allowance/ Minimum Requirements of Healthy Persons (Children)
Calcium	Adult: 6×10^{-8} Child: 6×10^{-8}	1.0 gm (4 years to adult)	0.6 gm (0-12 months) 0.8 gm (under 4 years)
Copper	Adult: 5×10^{-9} Child: 6×10^{-9}	2.0 mg (4 years to adult)	0.6 mg (0-12 months) 1.0 mg (under 4 years)
Zinc	Adult: 3×10^{-7} Child: 6×10^{-8}	15.0 mg (4 years to adult)	5 mg (0-12 months) 8 mg (under 4 years)
Sodium	Adult: 6×10^{-8} Child: 7×10^{-8}	500 mg (>18 yr)	225 mg (1 yr) 300 mg (2-5 yr) 400 mg (6-9 yr) 500 mg (10-18 yr)
Potassium	Adult: 8×10^{-6} Child: 1×10^{-5}	2000 mg	1000 mg (1 yr) 1400 mg (2-5 yr) 1600 mg (6-9 yr) 2000 mg (10-18 yr)

Section 5

UNCERTAINTY ANALYSIS

5.0 Uncertainty Analysis

This section discusses the variability and uncertainties in the HHRA process which may effect the estimated risks and hazards. Several factors, ranging from the use of surrogate data where no site-specific value is available, to the assumptions made by the risk assessors, can all lead to uncertainty.

The major types of uncertainty that may have affected this risk assessment are parameter uncertainty, model uncertainty, and scenario uncertainty.

Parameter uncertainty includes measurement errors, sampling errors, the limitations of equipment, methodology limitations, and human error.

Model uncertainty includes the use of surrogate variables and algorithms, the effect of unusual conditions, and exclusion of variables. Models and algorithms are subject to considerable uncertainty. For this reason, most models are designed to predict very conservative, or "high end" estimates.

Scenario uncertainty occurs due to the absence of information associated with exposure and intakes of individuals. Sources of scenario uncertainty include error in descriptive information, aggregation errors (assuming all individuals are the same), inaccurate professional judgment, and incomplete analysis (e.g. failure to consider all exposed individuals and major routes of exposure).

The different types of uncertainties encountered throughout the HHRA for the propellant bag burning at MMR are summarized below. The direction in which the estimated risks and hazards will take as impacted by each uncertainty is also shown below. In many instances, the direction of effect is variable; the risks and hazards may increase or decrease depending on the information obtained.

5.1 Parameter Uncertainty

5.1.1 Fate and Transport Modeling

The concentration of the COCs was assumed to be present in each media at an equilibrium concentration. Natural degradation processes such as photodegradation and environmental half-life of the COCs have not been included in the fate and transport modeling process. This approach tends to overestimate the risk.

The concentration of the COC was assumed to remain in the first centimeter of the soil layer, with the exception of the COC concentration in the soil for root uptake by vegetables. The actual mixing depth may be deeper depending on the potential for migration of each COC. This tends to overestimate the risk.

Fate and transport data was not available for several of the metals in the risk

assessment. These included calcium, copper, potassium, sodium and titanium. Consequently, these metals were not evaluated for uptake in belowground vegetables. They were assigned the same Kd_s, Kd_{sw} and Kd_{bs} values as cadmium, in order to allow the calculation of other media concentrations. The direction of uncertainty varies.

5.1.2 Chemical Specific Parameters and Biotransfer Uptake Factors

Outcomes from different studies have shown varying degrees of chemical-specific parameters and bio-uptake factors. Bio-uptake factors have also been shown to vary between species. Therefore, using a default value for all species will result in uncertainty. The direction of uncertainty varies.

5.1.3 Estimating the Watershed and Impervious Watershed Areas

These estimates are not readily available and require professional judgment from topographic maps and land use information. Professional judgment leaves room for uncertainty. The direction of the uncertainty varies.

5.1.4 Depth of Upper and Lower Shawnee

The depth of Upper and Lower Shawnee was not known. The risk assessors selected an average depth of 5 meters, based on the size of the pond and the depth of nearby local ponds. If the pond was in fact deeper, the risk was overestimated. If it was more shallow, the risk may have been underestimated.

5.1.5 Runoff, Evapotranspiration, and Rainfall Factor values

The runoff and evapotranspiration values were taken from the 1973 *Water Atlas of the United States* (Geraghty et al, 1973). These values are shown on isolines for general areas. Therefore, there is uncertainty associated with these values. A pond study done by Jacobs Engineering indicates that there is little runoff to these ponds; consequently, using a runoff value above zero tends to overestimate the risk. The direction of the Evapotranspiration uncertainty varies. Likewise, the Rainfall Factor, taken from *Erosion and Sediment Pollution Control* (Beasely, 1972) is based on isolines, and is therefore uncertain. The direction of uncertainty varies.

5.1.6 Volumetric Flow Rate (Vfx)

The Vfx was determined by multiplying the watershed area by the amount of annual runoff, and using this value. If the watershed area is incorrect, or if the runoff amount is inaccurate (see sections above), the Vfx would be incorrect. The direction of uncertainty varies.

5.1.7 Estimation of Wind Speeds

The wind speed used for surface winds were actually wind measurements for 10 meters above the earth's surface. This creates uncertainty. The direction of the uncertainty varies.

5.1.8 Swimming Water Uncertainty

For this HHRA, the numbers selected for days a year swimming in ponds effected by the propellant bag was 30 days a year, for 4 hours each time, while swallowing 50 milliliters of water each hour. These are greater than the numbers recommended by the USEPA and would overestimate the risk.

5.1.9 Length of Burn Time

In this HHRA, it is assumed that the propellant bag burning operations were in place from 1942 through 1992. If the propellant bag burning occurred less than the full 50 years, this might overestimate the risk. If the propellant bag burning occurred for more than the given 50 years, it might underestimate the risk.

5.1.10 Use of USEPA Default Parameters

The estimated risks and hazards are assumed to be applicable to the assessed individuals. Since not all individuals experience the same degree of exposure or the same sensitivity to chemicals, the HHRA focused on "highend" predictions. This tends to overestimate the risk.

5.1.11 Bang Box Facility Data

There is uncertainty associated with the test methods used in collecting the data from the Bang Box facility. This includes the inherent uncertainty of air sampling and laboratory methods. There is also uncertainty generated in that there may be compounds present that were not sampled for, and, consequently were not included in the HHRA. The direction of the uncertainty varies.

5.2 Model Uncertainty

5.2.1 Differentiating between Edible Portions of Fish

Based on the octanol-water partition coefficient (K_{ow}), a COC may partition more frequently to the liver, kidney, bone, and adipose tissue. Human consumption is usually limited to the fish fillet (although certain ethnic groups may consume other portions of the fish as well). This tends to overestimate the risk.

5.2.2 Assessment of Selected Pathways

The number of pathways evaluated in this HHRA were selected because they are believed by USEPA to contribute the most to risk and hazard estimates. Pathways such as dermal absorption, beef and milk consumption, breast milk ingestion, and game animal ingestion are not included in this HHRA. This tends to underestimate the risk.

5.2.3 Co-location of Maximum Air Concentrations and Depositions

Each receptor was assumed to be exposed to the maximum soil concentration, vegetable concentrations, surface water concentrations, and fish concentrations. In reality it is unlikely that the population was exposed to the maximums of all indirect sources. This tends to overestimate the indirect risks.

5.2.4 Burning Operation

This HHRA assumes that during the entire 50-year period the burning operation was essentially the same as it was during the years for which data was available. The direction of the uncertainty varies.

5.2.5 Toxicity Assessment

5.2.5.1 Absence of Toxicity Values

Toxicity values were available for all of the COCs that were evaluated. Some COCs do not exhibit carcinogenicity; therefore, they would not be expected to have CSFs. However, some COCs which are believed to have carcinogenic effects do not have slope factors, and some COCs which are known to have systemic effects, do not have RfDs or RfCs. This would underestimate the risk. The use of the ambient air risk-based screening levels (USEPA, 1997b), provided values for comparison; these values were based on oral potency slope and references where inhalation values were not available. Using these values increased the number of COCs that were quantitatively evaluated, but the use of the ingestion values may not be appropriate, and in some cases were used in instances where exposure via inhalation was very unlikely. Although the direction of the risk varies, it is more likely to overestimate the risk.

5.2.5.2 Modifying and Uncertainty Factors for Toxicity Values

Modifying factors and uncertainty factors of varying degree are typically applied to toxicological values. These factors are used to conservatively account for the uncertainty caused by extrapolating from animal studies for human health evaluation, and for the uncertainty caused by deriving a toxicity value from a study of one exposure, to another exposure route. These tend to overestimate the risk.

5.2.5.3 Cancer Slope Factors

Cancer slope factors are calculated by fitting a model to the data, and then using the upper 95th confidence limit of the slope of the resulting dose-response curve. The use of the upper 95th percent confidence limit is a conservative measure, and may result in overestimating risk. The models assume that there is no threshold for effect, also a conservative assumption.

5.2.5.4 Methyl Mercury

In this HHRA, it is assumed that all mercury in the indirect portion of the risk assessment has been converted to methyl mercury. It is very unlikely that 100% of the mercury in the environment would have been converted to methyl mercury. This is a conservative assumption, and tends to overestimate the risk.

5.2.5.6 Chemical Mixtures

The USEPA methodology does not evaluate the effects of the mixture of chemicals. The effects are assumed to be additive, although it is possible they could be synergistic or multiplicative. The direction of this uncertainty tends to underestimate the risk.

5.3 Scenario Uncertainty

5.3.1 Intake Uncertainties.

All intake calculations are based on assumptions on the amount of each type of food people eat (fish, aboveground vegetables, belowground vegetables), and how much is from their own gardens, or from fish they caught. Individuals may vary from the population norms determined by population studies. This introduces uncertainty. The direction of the uncertainty varies. For this HHRA, it was assumed that 100% of the fish eaten by the subpopulations came from fish they had caught, and that those fish came from the pond with the highest concentration of each of the COCs. These are conservative assumptions and create uncertainty that would tend to overestimate the risk.

5.3.2 Individual Variability

All individuals vary in their genetic makeup, their participation in outdoor activities, the amount of food they eat, and their lifestyle. Although most of the assumptions are high end, to take into account this variability, if an individual is markedly different than the population, their risk may be different, either higher or lower. The direction of uncertainty varies.

Section 6

COMMENTS

6.0 Comments

This document is open for review and public comment until July 13, 1998. Please address any comments to:

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Appendix A

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Appendix B

ALGORITHMS AND PARAMETERS

Soil Equations

(1) $$Sc = \frac{[Ds]}{ks * (T_c - T_1)} * \frac{[T_c + \exp(-ks * T_c]}{ks} - \frac{T_1 + [\exp(-ks * T_1)]}{ks}$$

(2) $$Sc_{Tc} = \frac{Ds * [1 - \exp(-ks * T_c)]}{ks}$$

(3) $$Ds = \frac{100 * [(0.31536 * V_{dv} * V_c + V_{wd}) + (P_{wd} + P_{dd})}{Z * BD}$$

(4) $$ks = ksl + ksr + kse + ksg + ksv$$

(5) $$ksl = \frac{P + I - R - Ev}{Z * (\Theta_s + Kd_s * BD)}$$ where kds values are less than 100L/kg

(6) $$ksr = \frac{R}{Z * (\Theta_s + Kd_s * BD)}$$ where kds values are less than 100 L/kg

(7) $$ksv = \frac{3.1526 \times 10^{-7} * H}{Z * Kd_s * R * T * BD} * [0.482 * u^{0.78]} * \frac{(U_a)^{-0.67}}{P_a * D_a} * [(4A)/3.14]^{-0.11/2}$$

Parameter	Definition	Default/Site Specific Value
Sc	Soil concentration, mg/kg	calculated
Sc_{Tc}	Maximum soil concentration over the period of deposition, unitless	calculated
ks	Soil loss concentration due to all processes, yr^{-1}	calculated
ksl	Loss constant due to leaching, yr^{-1}	calculated
ksr	Loss constant due to surface runoff, yr^{-1}	calculated
kse	Loss constant due to erosion, yr^{-1}	0
ksg	Loss constant due to degradation, yr^{-1}	chemical-specific
ksv	Loss constant due to volatilization, yr^{-1}	calculated

Parameter	Definition	Default/Site-Specific Value
P_{dd}	= Q*Dydp*(1-F_v), Yearly dry deposition from particle phase, g/m^2-yr	modeled
P_{wd}	= Q*Dywp*(1-F_v), Yearly wet deposition from particle phase, g/m^2-yr	modeled
V_{wd}	= Q*F_v*Dywv, Yearly wet deposition from vapor phase, g/m^2-yr	modeled
V_c	= Q*F_v*Cyv, Yearly vapor phase air concentration, μg/m^2	modeled
Q	Propellent bag emissions, g/sec)	modeled
F_v	Fraction of air concentration in vapor phase (dimensionless)	chemical-specific
Dydp	Normalized yearly dry deposition from particle phase, s/m^2/yr	modeled
Dywp	Normalized yearly wet deposition from particle phase, s/m^2/yr	modeled
Dywv	Normalized yearly wet deposition from vapor phase, s/m^2/yr	modeled
Cyv	Normalized vapor phase air concentration, ug-sec/g-m_3	modeled
V_{dv}	Dry deposition velocity, cm/s	3
Kd_s	Soil-water partition coefficient, cm^3/g or mL/g	chemical-specific
T_c	Total deposition time period, yr	site specific: 50
Sc_{Tc}	Soil concentration at time Tc, mg/kg	calculated
Ds	Deposition term, mg/kg-yr	calculated
T_1	Time before deposition, yr	0
T_2	Total exposure time period, yr	Adult: 30 Child: 6
Z	Soil mixing depth, cm	1
BD	Soil bulk density, g/cm^3	1.5

Paramter	Definition	Default/Site-Specific Value
Ev	Average annual evapotranspiration, cm/yr	site-specific: 31.75
P	Average annual precipitation, cm/yr	site-specific: 122.68
I	Average annual irrigation, cm/yr	0
R	Average annual runoff, cm/yr	25 cm/yr
Θ_s	Soil volumetric water content, cm^3/cm^3 or mL/cm^3	0.2
100	Units conversion factor, $mg\text{-}m^2/kg\text{-}cm^2$	

Aboveground Vegetable Equations

$$(8)\ Pd = \frac{1000 * [P_{dd} + (Fw * P_{wd})] * Rp * [1.0 - \exp(-kp * Tp)]}{Yp * kp}$$

$$(9)\ Pv = \frac{V_c * Bv * VG_{ag}}{\rho_a}$$

$$(10)\ Pr_{ag} = Sc * Br$$

Parameter	Definition	Default/Site-Specific Value
Pd	Concentration in plant due to direct deposition, mg/kg	calculated
Pv	Concentration in plant due to air-to-plant transfer, mg/kg	calculated
1000	Units conversion factor, mg/g	
Yp	Standing crop biomass of the edible portion of the plant, kg dry weight (DW)/m^2	1.7
V_c	Yearly vapor phase air concentration, $\mu g/m^2$	modeled
P_{dd}	$=Q*Dydp*(1-F_v)$, Yearly dry deposition from particle phase, g/m^2-yr	modeled

Parameter	Definition	Default/Site-Specific Value
P_{wd}	= Q*Dywp*(1-F_v), Yearly wet deposition from particle phase, g/m^2-yr	modeled
Fw	Wet deposition retention fraction, unitless	chemical-specific
kp	Plant surface loss coefficient, yr^{-1}	18
Tp	Length of plant exposure to depostion of edible portion of plant, per harvest, yr	0.16
VG_{ag}	Emperical correction factor for Aboveground vegetable, unitless	0.01
Rp	Interception fraction of edible portion of plant, unitless	0.04
Bv	Air-to-plant biotransfer factor, (mg substance/kg plant tissue DW)/(μg substance/g air)	chemical-specific
Br	Plant-soil bioconcentration factor, (μg substance/g plant tissue DW)/(μg substance/g soil)	chemical-specific
ρ_a	Density of air, g/m^3	$1.2x10^3$
Pr_{ag}	Concentration of substance in Aboveground plant parts due to root uptake, (mg/kg)	calculated
Sc	Soil concentration, mg/kg	calculated using Z= 1 cm

Root Vegetable Due to Deposition and Root Uptake

(11) $Pr_{bg} = \dfrac{Sc * RCF * VG_{bg}}{Kd_s}$

Parameter	Definition	Default/Site-Specific Value
Pr_{bg}	Concentration in belowground plant parts due to root uptake, mg/kg	calculated
Sc	Soil concentration, mg/kg	calculatedusing Z = 20 cm
RCF	Ratio of concentration in roots to concentration in soil pore water, (mg substance/kg plant tissue FW)/(μg substance/mL pore water)	chemical-specific
VG_{bg}	Belowground vegetable correction factor, unitless	0.01
Kd_s	Soil-water partition coefficient, cm^3/g or mL/g	chemical specific

Fish Concencentration Equations

(12) $C_{fish} = C_{dw} * BCF$ or

(13) $C_{fish} = C_{wt} * BAF$

(3) $Ds = \dfrac{100 * [(0.31536 * V_{dv} * V_c + V_{wd}) + (P_{wd} + P_{dd})]}{Z * BD}$

(14) $kse = \dfrac{0.1 * Xe * SD * ER * (K_{ds} * BD)}{BD * Z * [\Theta_s + Kd_s * BD]}$

(7) $ksv = \dfrac{3.1526 \times 10^{-7} * H}{Z * Kd_s * R * T * BD} * [0.482 * u^{0.78]} * \dfrac{(U_a)^{-0.67}}{P_a * D_a} * [(4A)/3.14]^{-0.11/2}$

(15) $L_T = L_{dep} + L_{RI} + L_R + L_E + L_{DIF}$

(16) $L_{dep} = [Vwdb + Pddb + Pwdb] * WA_w$

(17) $L_{RI} = Q [F_v * Dywwv + (1.0-F_v) * Dytwp] WA_I$

(18) $L_R = \dfrac{R * [WA_L - WA_I] * (Sc * BD) * 0.01}{(\Theta s + Kd_s * BD)}$

(19) $L_{DIF} = \dfrac{K_v * V_{cb} * Cywv * WA_w * 10^{-6}}{[H/TR]}$

(20) $L_E = \dfrac{Xe * [WA_L - WA_I] * SD * ER * (Sc * Kd_s * BD) * 0.001}{(\Theta_s + Kd_s * BD)}$

(21) $Xe = \dfrac{RF * K * LS * C * P * 907.18}{4047}$

(22) $SD = a * [WA_L]^{-b}$

(23) $C_{wtot} = \dfrac{L_T}{Vfx * f_{water} + k_{wt} * WA_w * [d_w + d_b]}$

(24) $f_{water} = \dfrac{(1 + Kd_{sw} * TSS * 10^{-6}) * d_w}{(1 + Kd_{sw} * TSS * 10^{-6}) * d_w + [\Theta_{bs} + Kd_{bs} * BS] * d_b}$

(25) $f_{benth} = 1 - f_{water}$

(26) $k_{wt} = f_{water} * k_v + f_{benth} * k_b$

(27) $k_v = \dfrac{K_v}{D_z * (1 + Kd_{sw} * Tss * 10^{-6})}$

(28) $K_v = [K_L^{-1} + (K_G * H/RT_k)^{-1}]^{-1} * \mathit{0}^{(Tk-293)}$

(29) $K_L = (Cd^{0.5} * W) * (P_a/P_w)^{0.5} * k^{0.33}/Lamba_2) * (u_w/[P_w * D_w])^{-0.67} * 3.15x10^{-7}$

(30) $K_G = (Cd^{0.5} * W) * k^{0.33}/Lamba_2) * (u_w/[P_w * D_w])^{-0.67} * 3.15x10^{-7}$

(31) $k_b = \dfrac{Xe * WA_L * SD * 10^3 - Vfx * TSS}{WA_W * TSS} * \dfrac{TSS * 10^{-6}}{BS * d_b}$

(32) $C_{wt} = f_{water} * C_{wtot} * [(d_w + d_b)/d_w]$

(33) $C_{dw} = \dfrac{C_{wt}}{1 + Kd_{sw} * TSS * 10^{-6}}$

(24) $C_{sb} = \dfrac{f_{benth} * C_{wtot} * Kd_{bs} * [d_w + d_b]}{[\Theta_{bs} + Kd_{bs} * BS] * d_b}$

Parameter	Definition	Default/Site-Specific Value
Pwds	= Q*(1-F_v)*Dywwp; Yearly watershed wet deposition from particle phase, g/m2/yr	modeled
Pdds	= Q*(1-F_v)*Dydwp; Yearly watershed dry depostion from particle phase, g/m2-yr	modeled
Vwds	= Q*F_v*Dywwv; Yearly watershed wet deposition from vapor phase, g/m2-yr	modeled
V_{cs}	= Q*F_v*Cywwv; Yearly watershed average vapor phase air concentration, ug/m3	modeled
Pwdb	= Q*(1-F_v)*Dywp; Yearly waterbody wet depostion from particle phase, g/m2-yr	modeled
Pddb	= Q*(1-F_v)*Dydp; Yearly waterbody dry depostion from particle phase, g/m2-yr	modeled
Vwdb	= Q*F_v*Dywv; Yearly waterbody wet depostion from vapor phase, g/m2-yr	modeled
V_{cb}	= Q*F_v*Cywv; Yearly waterbody average vapor phase air concentration, ug/m3	modeled
kse	Loss constant due to soil erosion, yr^{-1}	calculated
0.1	Units conversion factor, kg-cm^2/g-m^2	
Xe	Unit soil loss, kg/m^2-yr	calculated
SD	Watershed sediment delivery ratio, unitless	calculated
ER	Soil enrichment ratio, unitless	3
Kd_s	Soil-water partition coefficient, L/kg	chemical-specific
3.1536×10^{-7}	Units Conversion Constants, s/yr	
R	Universal gas constant, atm-m^3/mol-K	8.205×10^{-5}
T	Ambient Air Temperature, K	Site Specific
u	Average annual windspeed, m/s	Site Specific

Parameter	Definition	Default/Site-Specific Value
BD	Soil bulk density, g/cm^3	1.5
Z	Soil mixing depth, cm	1
u_a	Viscosity of air, g/cm-s	1.81×10^{-4}
P_a	Density of air, g/cm^3	1.2x 10-3
D_a	Diffusitivity of COC in air, cm^2/s	Chemical Specific
A	Surface area of contaminated area, m^2	See Table 3-1
L_T	Total substance load to the waterbody, g/yr	calculated
k_v	Water column volatization rate	calculated
k_b	Benthic burial rate constant	calculated
K_v	Overall transfer rate, m/yr	calculated
K_L	Liquid phase transfer coefficient, m/yr	calculated
K_G	Gas phase transfer coefficient, m/yr	calculated
T_k	Waterbody temperature, K	298
O	Temperature correction factor, unitless	1.026
Cd	Drag Coefficient	.0011
W	Wind velocity at 10m above water surface, m/s	site-specific: 4.11
k	Von Karman's constant	0.4
$Lamba_2$	Dimensionless viscous sublayer thickness	4
u_w	Viscosity of water corresponding to water temp, g/cm-s	1.69×10^{-2}
3.15×10^{-7}	Conversion constant, s/yr	
L_{dep}	Deposition of particle bound substance to the waterbody, g/yr	calculated
L_{RI}	Runoff load from impervious surfaces, g/yr	calculated
L_R	Runoff load from pervious surfaces, g/yr	calculated

Parameter	Definition	Default/Site-Specific Value
L_E	Soil erosion load, g/yr	calculated
WA_w	Waterbody area, m^2	see Table 3-1
WA_I	Impervious watershed area, m^2	see Table 3-1
0.01	Units conversion factor, $kg\text{-}cm^2/mg\text{-}m^2$	
R	Average annual runoff, cm/yr	site-specific: 25
WA_L	Total watershed area, m^2	site-specific
Sc	Soil concentration, mg/kg	calculated using Z = 1 cm
0.001	Units conversion factor, (g/kg)/(mg/kg)	
RF	USLE rainfall (or erosivity) factor, 1/yr	site-specific: 135
K	USLE erodibility factor, ton/acre	0.36
LS	USLE length-slope factor, unitless	1.5
C	USLE cover management factor, unitless	0.1
P	USLE supporting practice factor, unitless	1
907.18	Conversion factor, kg/ton	
4047	Conversion factor, km^2/acre	
b	Empirical slope coefficient, unitless	0.125
a	Empirical intercept coefficient, unitless	watershed area dependent
C_{wtot}	Total waterbody concentration, including water column and bed sediment, mg/L	calculated
Vfx	Average volumetric flow rate, m^3/yr	see Table 3-1
f_{water}	Fraction of total waterbody substance concentration that occurs in the water column, unitless	calculated
d_w	Depth of the water column, m	see Table 3-1
d_b	Depth of upper benthic layer, m	0.03
d_z	Total waterbody depth	calculated: $d_w + d_b$
Kd_{sw}	Suspended sediment/surface water partition coefficient, L/kg	calculated

Parameter	Definition	Default/Site-Specific Value
TSS	Total suspended solids, mg/L	10
10^{-6}	Units conversion factor, kg/mg	
Θ_{bs}	Bed sediment porosity, L water/L	0.5
BS	Bed sediment concentration, g/cm^3	1.0
f_{benth}	Fraction of total waterbody substance concentration that occurs in the bed sediment, unitless	calculated
C_{wt}	Total concentration in water column, mg/L	calculated
k_{wt}	Total waterbody dissipation rate constant, yr^{-1}	calculated
C_{dw}	Dissolved phase water concentration, mg/L	calculated
C_{sb}	Concentration sorbed to bed sediments, mg/kg	calculated
Kd_{bs}	Bottom sediment-sediment pore water partition coefficient, mg/kg	calculated
C_{fish}	Concentration in fish, mg/kg	calculated
f_{lipid}	Fish lipid content, unitless	0.07
OC_{sed}	Fraction organic carbon in bottom sediment, unitless	0.04
BSAF	Biota to sediment accumulation factor, unitless	chemical-specific
BCF	Bioconcentration factor, L/kg	chemical-specific
BAF	Bioaccumulation factor, L/kg	chemical-specific

Soil Intake

(35) $I_{soil} = Sc * CR_{soil} * F_{soil}$

Aboveground Vegetable Intake

(36) $I_{ag} = [Pd + Pv + Pr] * CR_{ag} * F_{ag}$

Root Vegetable Intake

(37) $I_{bg} = Pr_{bg} * CR_{bg} * F_{bg}$

Fish Intake

(38) $I_{fish} = C_{fish} * CR_{fish} * F_{fish}$

Surface Water Intake

(39) $I_{sw} = \frac{C_{wtot} * CR_{sw} * ET_{sw} * ET_{sw} * EF_{sw}}{365}$

Total Intake

(40) $I_{tot} = I_{soil} + I_{ag} + I_{bg} + I_{fish} + I_{sw}$

Parameter	Definition	Default/Site-Specific Value
I_{soil}	Daily intake of substance from soil, mg/day	calculated
Sc	Soil concentration after total exposure period, mg/kg	calculated
CR_{soil}	Consumption rate of soil, kg/day	Adult: 0.0001 Child: 0.0002
F_{soil}	Fraction of soil impacted, unitless	1
I_{bg}	Daily intake of substance from root vegetables, mg/day	calculated
CR_{bg}	Consumption rate of root vegetables, kg/day	Adult: 0.0063 Child: 0.0014
F_{bg}	Fraction of root vegetables impacted, unitless	Adult, child: 0.25
I_{ag}	Daily intake of substance from aboveground vegetables, mg/day	calculated
Pd	Concentration in plant due to direct deposition, mg/kg	calculated
Pv	Concentration in plant due to air-to-plant transfer, mg/kg	calculated
CR_{ag}	Consumption rate of aboveground vegetables, kg/day	Adult: 0.024 Child: 0.005
F_{ag}	Fraction of aboveground vegetables impacted, unitless	Adult, child: 0.25

Parameter	Definition	Default/Site-Specific Value
Pr_{bg}	Concentration in plant due to root uptake, mg/kg	calculated
CR_{sw}	Contact rate with surface water (L/hr)	default: 0.05
ET_{sw}	Exposure time to surface water (hr/day)	site-specific: 4
EF_{sw}	Exposure frequency (dy/yr)	site-specific: 30
365	Averaging Time	
I_{fish}	Daily intake of substance from fish, mg/kg	calculated
C_{fish}	Concentration in fish, mg/kg	calculated
CR_{fish}	Consumption rate of fish, kg/day	0.059
F_{fish}	Fraction of fish impacted, unitless	1
C_{dw}	Dissolved substance concentration in drinking water, mg/L	calculated
I_{tot}	Total daily intake of COC, mg/day	calculated

Cancer Risks, Hazard Quotients, and Hazard Indices Due to Indirect Exposures

Indirect Cancer Risk

(41) $$\text{Indirect Cancer Risk} = \frac{I_{tot} * ED * EF * CSF}{BW * AT * 365}$$

Indirect Hazard Quotients

(42) $$HQ = \frac{I_{tot}}{BW * RfD}$$

Indirect Hazard Index

(43) $HI = \sum HQ$

Total Indirect Cancer Risk

(44) $\text{Total Indirect Cancer Risk} = \sum \text{Indirect Cancer Risks}$

Parameter	Definition	Default/Site-Specific Value
Indirect Cancer Risk	Excess lifetime cancer risk from indirect exposures, unitless	calculated
I_{tot}	Total daily intake of substance, mg/day	calculated
ED	Exposure duration	Adult: 30 Child: 6
EF	Exposure frequency, day/yr	350
CSF	Oral cancer slope factor, $(mg/kg\text{-}day)^{-1}$	chemical-specific
BW	Body weight, kg	Adult: 70 Child: 15
AT	Averaging time, yr	70
365	Units conversion factor, day/yr	
HQ	Hazard quotient from indirect exposures, unitless	calculated
RfD	Reference dose, mg/kg-day	chemical-specific

Intakes, Cancer Risk and Hazard Due to Inhalation, Grand Total Cancer Risk

Cancer Inhalation Intake

(45) Cancer Inhalation Intake $= \dfrac{C_{air}*IR*ET*EF*ED*0.001}{BW * LT}$

Inhalation Cancer Risk

(46) ADI_{inh} = Cancer Inhalation Intake * Inhalation CSF

Inhalation Hazard Quotient

(47) $HQ_{inh} = \dfrac{C_{air} * 0.001}{RfC}$

Inhalation Hazard Index

(48) $Hi_{inh} = \sum HQ_{inh}$

Total Inhalation Cancer Risk

(49) Total inhalation Risk $= \sum$ Inhalation Cancer Risks

Grand Total Cancer Risk

(50) Grand Total Cancer Risk = Indirect Cancer Risk + Inhalation Cancer Risk

Parameter	Definition	Default/Site-Specific Value
ADI_{inh}	Average daily intake of carcinogenic substance from inhalation, mg/kg-day	calculated
C_{air}	Respirable Concentration, $\mu g/m^3$	modeled
IR	Inhalation rate, m^3/hr	Adult: 1.0 Child: 0.2
ET	Exposure time, hr/day	24
EF	Exposure frequency, day/yr	365
ED	Exposure duration, yr	30
0.001	Units conversion factor, $mg/\mu g$	
BW	Body weight, kg	Adult: 70 child: 15
LT	Number of days in a lifetime, day	25550
Inhalation Cancer Risk	Excess lifetime cancer risk from inhalation, unitless	calculated
Inhalation CSF	Inhalation cancer slope factor, $(mg/kg\text{-}day)^{-1}$	chemical-specific
HQ_{inh}	Hazard quotient for substance from inhalation, unitless	calculated
RfC	Inhalation reference concentration, mg/m^3	chemical-specific
Grand Total Cancer Risk	Excess lifetime cancer risk from indirect exposure and direct inhalation, unitless	calculated

Appendix C

PROPELLANT BAG BURNING DATA, 1985-1994

The following assumptions were made if this specific data was not recorded in the firing and burning records.between 1986-1994:

1. Table C-1 lists the assumed charge and therefore the assumed number of increments that were burned for each round of artillery or mortar fired. These numbers were the most often noted charges found on the firing records.

Table C-1. Assumed Charge Load.

Artillery/Mortar	*Charge*
155-mm	3 (2 bags left over)
105-mm	4 (3 bags left over)
81-mm	4 (5 bags left over)
60-mm	3 (1 bag left over)
4.2-in (or 107-mm)	10 (31 "cheese" left over)

2. While the firing positions were not readily noted on the records, it was assumed that the same military unit stayed at the same firing positions for the same training day. Therefore, if one firing record had a designated firing point, this was used for all records marked with the same unit and date.

3. If a mortar record did not contain which type of mortar was fired, it was assumed to be an 81-mm mortar.

4. If an artillery record did not contain which type of artillery was fired, it was assumed to be a 155-mm howitzer.

Table C-2: M1 Propellant Burn Data for 1986

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
3-Jan-86	GP16	155mm	224	198.80
3-Jan-86	GP20	155mm	224	198.80
3-Jan-86	GP22	155mm	208	184.60
7-Feb-86	GP9	155mm	146	176.11
8-Feb-86	GP11	105mm	64	31.56
8-Feb-86	GP14	105mm	92	45.37
8-Feb-86	GP18	105mm	72	35.51
8-Feb-86	GP18	105mm	16	7.89
8-Feb-86	GP20	105mm	76	37.48
8-Feb-86	GP20	105mm	160	78.90
8-Feb-86	GP6	105mm	80	39.45
8-Feb-86	GP7	105mm	72	35.51
8-Feb-86	GP8	105mm	80	39.45
8-Feb-86	GP10	155mm	50	60.31
8-Feb-86	GP11	155mm	58	69.96
8-Feb-86	GP9	155mm	146	176.11
8-Feb-86	GP9	155mm	32	38.60
9-Feb-86	GP10	155mm	66	79.61
9-Feb-86	GP11	155mm	66	79.61
9-Feb-86	GP9	155mm	66	79.61
1-Mar-86	GP6	155mm	150	180.94
1-Mar-86	GP7	155mm	148	149.76
1-Mar-86	GP8	155mm	80	96.50
8-Mar-86	GP14	105mm	172	84.82
8-Mar-86	GP14	105mm	96	47.34
8-Mar-86	GP18	105mm	16	7.89
8-Mar-86	GP18	105mm	208	102.57
8-Mar-86	GP20	105mm	76	37.48
8-Mar-86	GP20	105mm	56	27.62
8-Mar-86	GP8	105mm	244	120.32
8-Mar-86	GP10	155mm	180	217.13
8-Mar-86	GP11	155mm	180	217.13
8-Mar-86	GP9	155mm	180	217.13
22-Mar-86	GP6	105mm	132	76.62
22-Mar-86	GP7	105mm	182	121.89
22-Mar-86	GP8	105mm	120	59.18
22-Mar-86	GP14	155mm	60	91.13
22-Mar-86	GP22	155mm	52	78.98
22-Mar-86	GP9	155mm	64	97.20
12-Apr-86	GP10	105mm	128	63.12
12-Apr-86	GP10	105mm	192	94.68
12-Apr-86	GP11	105mm	112	55.23
12-Apr-86	GP11	105mm	16	7.89
12-Apr-86	GP24	105mm	28	13.81
12-Apr-86	GP8	105mm	24	11.84
12-Apr-86	GP9	105mm	28	13.81
12-Apr-86	GP9	105mm	124	61.15
1-May-86	GP6	155mm	172	207.48
1-May-86	GP8	155mm	112	135.10
1-May-86	GP9	155mm	128	154.40
3-May-86	GP12	105mm	60	29.59
3-May-86	GP12	105mm	16	7.89
3-May-86	GP16	105mm	88	43.40
3-May-86	GP18	105mm	80	39.45
3-May-86	GP18	105mm	100	47.34
18-Oct-86	GP7	155mm	56	67.55
3-May-86	GP22	105mm	80	39.45
3-May-86	GP22	105mm	92	43.40
3-May-86	GP6	105mm	92	45.37
3-May-86	GP7	105mm	100	49.31
3-May-86	GP8	105mm	220	108.49
31-May-86	GP11	105mm	24	11.84
31-May-86	GP24	105mm	100	49.31
31-May-86	GP24	105mm	78	45.27
31-May-86	GP7	105mm	16	7.89
31-May-86	GP7	105mm	78	45.27
31-May-86	GP8	105mm	196	96.65
31-May-86	GP8	105mm	54	31.34
7-Jun-86	GP14	155mm	98	115.80
7-Jun-86	GP16	155mm	136	164.05
7-Jun-86	GP20	155mm	136	164.05
7-Jun-86	GP6	155mm	198	183.38
21-Jun-86	GP14	105mm	215	141.81
21-Jun-86	GP20	105mm	124	71.39
21-Jun-86	GP22	105mm	90	52.24
21-Jun-86	GP11	155mm	52	62.73
21-Jun-86	GP8	155mm	86	79.61
21-Jun-86	GP9	155mm	62	74.79
22-Jun-86	GP14	105mm	12	8.51
22-Jun-86	GP20	105mm	21	12.19
22-Jun-86	GP22	105mm	12	8.51
28-Jun-86	GP11	105mm	20	9.86
28-Jun-86	GP6	105mm	188	92.71
28-Jun-86	GP7	105mm	256	126.24
28-Jun-86	GP8	105mm	128	63.12
28-Jun-86	GP9	105mm	128	63.12
28-Jun-86	GP11	155mm	10	12.06
28-Jun-86	GP6	155mm	94	113.39
28-Jun-86	GP7	155mm	128	154.40
28-Jun-86	GP8	155mm	64	77.20
28-Jun-86	GP9	155mm	64	77.20
13-Sep-86	GP10	155mm	164	197.83
13-Sep-86	GP14	155mm	98	115.80
13-Sep-86	GP16	155mm	136	164.05
13-Sep-86	GP20	155mm	136	164.05
13-Sep-86	GP9	155mm	166	200.24
27-Sep-86	GP6	105mm	148	72.98
27-Sep-86	GP7	105mm	152	74.96
27-Sep-86	GP8	105mm	20	9.86
27-Sep-86	GP8	105mm	132	65.09
4-Oct-86	GP10	155mm	128	154.40
4-Oct-86	GP11	155mm	100	120.63
4-Oct-86	GP14	155mm	56	67.55
4-Oct-86	GP17	155mm	68	82.03
4-Oct-86	GP18	155mm	68	82.03
4-Oct-86	GP20	155mm	80	96.50
4-Oct-86	GP22	155mm	56	67.55
4-Oct-86	GP24	155mm	104	125.45
4-Oct-86	GP6	155mm	82	98.91
4-Oct-86	GP7	155mm	82	98.91
18-Oct-86	GP6	155mm	256	308.80
18-Oct-86	GP8	155mm	52	62.73

25-Oct-86	GP10	155mm	48	57.90
25-Oct-86	GP9	155mm	92	118.21
1-Nov-86	GP12	105mm	96	47.34
1-Nov-86	GP14	105mm	128	63.12
1-Nov-86	GP16	105mm	128	63.12
1-Nov-86	GP18	105mm	16	7.89
1-Nov-86	GP9	155mm	14	21.26
1-Nov-86	GP9	155mm	11	16.71
1-Nov-86	GP9	155mm	7	10.63
1-Nov-86	GP9	155mm	6	9.11
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	4	6.08
1-Nov-86	GP9	155mm	3	4.56
1-Nov-86	GP9	155mm	3	4.56
1-Nov-86	GP9	155mm	3	4.56
22-Nov-86	GP16	155mm	200	241.25
22-Nov-86	GP22	155mm	192	231.60

Table C-3: M9 Propellant Burn Data for 1986

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
3-Jan-86	MP1	60mm	326	2.04
11-Jan-86	MP1	60mm	125	0.78
11-Jan-86	MP4	81mm	1170	27.24
8-Feb-86	MP4	81mm	250	5.82
8-Feb-86	MP7	81mm	1055	24.57
9-Feb-86	MP2	81mm	220	5.12
8-Mar-86	MP4	81mm	435	10.13
8-Mar-86	MP2	107mm	1240	20.75
22-Mar-86	MP4	81mm	132	3.07
23-Mar-86	MP6	81mm	380	8.85
5-Apr-86	MP3	107mm	1550	25.94
19-Apr-86	MP1	81mm	25	0.58
19-Apr-86	MP2	81mm	80	1.86
3-May-86	MP1	81mm	500	11.64
3-May-86	MP3	107mm	1240	20.75
10-May-86	MP4	81mm	400	9.31
17-May-86	MP3	60mm	7	0.04
19-May-86	MP6	81mm	500	11.64
20-May-86	MP6	81mm	450	10.48
7-Jun-86	MP3	81mm	50	1.16
9-Jun-86	MP7	81mm	750	17.46
21-Jun-86	MP2	81mm	462	10.76
21-Jun-86	MP4	107mm	1500	25.10
11-Aug-86	MP2	81mm	550	12.81
12-Aug-86	MP2	81mm	750	17.46
12-Aug-86	MP3	81mm	270	6.29
12-Aug-86	MP5	107mm	800	13.39
13-Aug-86	MP3	60mm	55	0.34
14-Aug-86	MP1	81mm	385	8.97
14-Aug-86	T-Range	81mm	695	16.18
14-Aug-86	MP3	107mm	6696	112.06
14-Aug-86	MP5	107mm	1333	22.31
15-Aug-86	MP1	81mm	540	12.57
15-Aug-86	MP3	107mm	5580	93.39
15-Aug-86	MP5	107mm	620	10.38
16-Aug-86	MP3	60mm	104	0.65
16-Aug-86	MP1	81mm	920	21.42
16-Aug-86	MP3	81mm	250	5.82
16-Aug-86	MP3	107mm	744	12.45
18-Aug-86	MP4	107mm	279	4.67
19-Aug-86	MP1	81mm	332	7.73
19-Aug-86	MP3	81mm	235	5.47
19-Aug-86	MP4	107mm	900	15.06
20-Sep-86	MP6	81mm	1530	142.51
4-Oct-86	MP2	81mm	755	17.58
4-Oct-86	MP3	81mm	1302	30.32
4-Oct-86	MP4	81mm	90	2.10
5-Oct-86	MP6	81mm	360	8.38
1-Nov-86	MP2	81mm	388	9.03
22-Nov-86	IBC	60mm	70	0.44
22-Nov-86	MP4	60mm	117	0.73
22-Nov-86	MP3	107mm	3596	60.18
22-Nov-86	MP6	107mm	1550	25.94

Table C-4: M1 Propellant Burn Data for 1987

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
7-Feb-87	GP18	105mm	16	7.89
7-Feb-87	GP14	105mm	128	63.12
7-Feb-87	GP12	105mm	96	47.34
7-Feb-87	GP7	105mm	224	110.46
7-Feb-87	GP8	105mm	256	126.24
8-Feb-87		155mm	320	386.00
7-Mar-87	GP8	105mm	72	35.51
7-Mar-87	GP7	105mm	104	51.29
7-Mar-87	GP6	105mm	88	43.40
7-Mar-87	GP14	105mm	90	52.24
7-Mar-87	GP9	155mm	36	43.43
7-Mar-87	GP10	155mm	36	43.43
7-Mar-87	GP11	155mm	44	53.08
2-May-87		155mm	146	221.74
2-May-87		155mm	294	354.64
16-May-87		155mm	352	424.60
18-Sep-87		155mm	240	289.50
26-Sep-87		155mm	354	427.01
3-Oct-87		155mm	324	390.83
17-Oct-87		155mm	154	185.76

Table C-5: M9 Propellant Burn Data for 1987

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
7-Mar-87	MP4	81mm	225	5.24
15-Nov-87	MP3	81mm	3840	89.42
17-Nov-87		60mm	146	0.91
17-Nov-87		107mm	2378	39.80
21-Nov-87	MP1	60mm	163	1.02
21-Nov-87	MP3	81mm	230	5.36
21-Nov-87	MP4	107mm	230	3.85

Table C-6: M1 Propellant Burn Data for 1988

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
4-Mar-88		155mm	70	84.45
16-Mar-88		155mm	46	55.49
19-Mar-88		155mm	332	400.54
14-Apr-88		155mm	24	28.95
16-Apr-88		155mm	292	352.26
23-Apr-88		155mm	270	325.45
5-May-88		155mm	40	48.27
14-May-88		155mm	156	188.23
21-May-88		155mm	92	110.99
25-Jun-88		155mm	168	202.69
15-Oct-88		155mm	191	272.63
5-Nov-88		155mm	532	641.87

Table C-7: M9 Propellant Burn Data for 1988

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
23-Apr-88		107mm	930	15.61
23-Apr-88	MP1	60mm	38	0.64
10-May-88		107mm	558	9.37
14-May-88		107mm	3224	54.12
14-May-88		81mm	495	11.53
27-Jun-88		107mm	372	6.24
27-Jun-88		60mm	49	0.82
27-Jun-88		81mm	160	3.73
28-Jun-88		107mm	62	1.04
28-Jun-88		81mm	665	15.49
29-Jun-88		81mm	465	10.83
30-Jun-88		60mm	25	0.42
30-Jun-88		81mm	520	12.11
1-Jul-88		107mm	1085	18.21
1-Jul-88		81mm	495	11.53
2-Jul-88		81mm	640	14.90
27-Jul-88		60mm	29	0.49
27-Jul-88		81mm	320	7.45
28-Jul-88		81mm	855	19.91
30-Jul-88	MP6	81mm	1265	29.46
31-Jul-88		81mm	155	3.61
15-Oct-88		107mm	186	3.12
29-Oct-88		81mm	300	6.99
30-Oct-88		81mm	85	1.98
5-Nov-88		107mm	3317	55.68
5-Nov-88		81mm	395	9.20

Table C-8: M1 Propellant Burn Data for 1989

Date of Firing.	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
1989	GP6	155mm	351	357.58
1989	GP7	155mm	252	303.98
1989	GP8	155mm	140	168.88
1989	GP9	155mm	270	275.06
1989	GP10	155mm	324	390.83
1989	GP11	155mm	288	347.40
1989	GP12	155mm	150	180.94
1989	GP14	155mm	224	270.20
1989	GP16	155mm	364	439.08
1989	GP17	155mm	86	103.74
1989	GP18	155mm	86	103.74
1989	GP20	155mm	516	525.68
1989	GP22	155mm	552	562.35

Table C-9: M9 Propellant Burn Data for 1989

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
1989	MP1	60mm	452	3.81
1989	MP1	81mm	4278	99.62
1989	MP2	107mm	23232	389.97
1989	MP2	60mm	186	1.57
1989	MP2	81mm	1758	40.94
1989	MP3	107mm	12375	207.72
1989	MP3	81mm	3270	76.14
1989	MP4	107mm	23925	401.60
1989	MP4	81mm	4278	99.62
1989	MP5	107mm	6468	108.57
1989	MP5	81mm	1002	23.33
1989	MP6	81mm	3522	82.01
1989	MP7	81mm	4026	93.75
1989	MP8	81mm	3042	70.84

Table C-10: M1 Propellant Burn Data for 1990

Date of Firing	Gun Point	Artillery Type	Increments Burned	Propellant Weight Burned (lbs)
03-Mar-90	GP6	155mm	32	38.60
03-Mar-90	GP7	155mm	138	166.46
24-Mar-90	GP6	155mm	118	142.34
24-Mar-90	GP7	155mm	96	115.80
24-Mar-90	GP9	155mm	80	96.50
24-Mar-90	GP10	155mm	77	92.32
24-Mar-90	GP16	155mm	46	69.86
24-Mar-90	GP18	155mm	88	107.40
24-Mar-90	GP20	155mm	92	110.98
07-Apr-90	GP6	155mm	32	38.60
07-Apr-90	GP7	155mm	48	48.90
07-Apr-90	GP8	155mm	32	38.60
07-Apr-90	GP14	155mm	50	60.31
07-Apr-90	GP20	155mm	68	82.03
07-Apr-90	GP22	155mm	42	50.66
28-Apr-90	GP14	155mm	92	110.98
28-Apr-90	GP22	155mm	10	12.06
05-May-90	GP6	155mm	24	28.95
05-May-90	GP7	155mm	48	48.90
05-May-90	GP8	155mm	24	28.95

Table C-11: M9 Propellant Burn Data for 1990

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
17-Mar-90	MP1	81mm	167	3.89
17-Mar-90	MP2	81mm	162	3.77
07-Apr-90	MP4	81mm	261	6.08
07-Apr-90	MP7	60mm	54	0.34
21-Apr-90	MP1	60mm	96	0.60
21-Apr-90	MP7	60mm	65	0.41
28-Apr-90	MP1	81mm	48	1.12
28-Apr-90	MP7	81mm	25	0.58
05-May-90	MP1	81mm	180	4.19
05-May-90	MP3	81mm	672	15.65
05-May-90	MP6	81mm	610	14.20
05-May-90	MP7	107mm	2332	39.14
05-May-90	MP8	81mm	560	13.04
10-Jun-90	MP1	81mm	884	20.58
10-Jun-90	T-Range	81mm	174	4.05
02-Aug-90	MP1	60mm	308	1.93

Table C-12: M1 Propellant Burn Data for 1991

Date of Firing	Gun Point	Artillery Type	Propellant Weight Burned (lbs)
9-Mar-91	GP-10	155mm	82.030
9-Mar-91	GP-11	155mm	79.610
9-Mar-91	GP-9	155mm	79.610
23-Mar-91	GP-11	155mm	125.450
23-Mar-91	GP-12	155mm	120.650
23-Mar-91	GP-14	155mm	33.750
23-Mar-91	GP-16	155mm	139.930
23-Mar-91	GP-20	155mm	144.750
23-Mar-91	GP-7	155mm	125.450
23-Mar-91	GP-9	155mm	110.975
14-Apr-91	GP-10	155mm	193.000
14-Apr-91	GP-11	155mm	96.450
14-Apr-91	GP-9	155mm	193.000
20-Apr-91	GP-14	155mm	82.025
20-Apr-91	GP-16	155mm	79.610
20-Apr-91	GP-20	155mm	79.610
23-Apr-91	GP-6	105mm	96.730
24-Apr-91	GP-6	105mm	89.520
24-Apr-91	GP-6	105mm	145.820
25-Apr-91	GP-6	105mm	49.090
25-Apr-91	GP-8	105mm	28.875
26-Apr-91	GP-8	105mm	43.310
27-Apr-91	GP-6	105mm	67.860
28-Apr-91	GP-8	105mm	15.880
29-Apr-91	GP-6	105mm	79.410
4-May-91	GP-6	155mm	48.250
4-May-91	GP-7	155mm	79.610
4-May-91	GP-8	155mm	45.750
5-Jun-91	GP-10	155mm	55.490
5-Jun-91	GP-6	155mm	50.660
5-Jun-91	GP-8	155mm	36.190
6-Jun-91	GP-17	155mm	21.710
6-Jun-91	GP-24	155mm	19.300
6-Jun-91	GP-6	155mm	38.600
6-Jun-91	GP-8	155mm	60.310
7-Jun-91	GP-14	155mm	50.660
7-Jun-91	GP-17	155mm	67.550
7-Jun-91	GP-24	155mm	24.125
8-Jun-91	GP-14	155mm	84.440
8-Jun-91	GP-20	155mm	50.660
8-Jun-91	GP-22	155mm	45.830
8-Jun-91	GP-6	155mm	38.600
8-Jun-91	GP-7	155mm	38.600
8-Jun-91	GP-8	155mm	38.600
9-Jun-91	GP-14	155mm	147.160
9-Jun-91	GP-20	155mm	55.490
9-Jun-91	GP-22	155mm	139.930
5-Oct-91	GP-17	155mm	62.730
5-Oct-91	GP-20	155mm	82.030
5-Oct-91	GP-22	155mm	57.900
5-Oct-91	GP-22	155mm	69.960

Table C-13: M9 Propellant Burn Data for 1991

Date of Firing	Mortar Point	Mortar Type	Propellant Weight Burned (lbs)
2-Jan-91	MP-1	107mm	26.970
7-Mar-91	MP-6	60mm	0.067
8-Mar-91	MP-3	60mm	0.135
16-Mar-91	MP-1	81mm	3.260
16-Mar-91	MP-3	60mm	1.990
6-Apr-91	MP-1	60mm	0.093
6-Apr-91	MP-1	81mm	7.990
6-Apr-91	MP-4	60mm	0.034
6-Apr-91	MP-6	60mm	1.854
6-Apr-91	MP-7	60mm	5.600
6-Apr-91	MP-8	60mm	31.650
20-Apr-91	MP-1	81mm	1.547
20-Apr-91	MP-2	107mm	6.861
24-Apr-91	MP-1	60mm	0.759
25-Apr-91	MP-1	107mm	21.610
27-Apr-91	MP-3	81mm	3.400
28-Apr-91	MP-3	81mm	0.955
29-Apr-91	MP-1	60mm	0.236
29-Apr-91	MP-1	60mm	2.520
29-Apr-91	MP-3	81mm	2.003
4-May-91	MP-1	107mm	17.154
4-May-91	MP-2	81mm	0.953
4-May-91	MP-3	107mm	30.876
4-May-91	MP-4	107mm	30.876
4-May-91	MP-4	81mm	1.589
4-May-91	MP-4	81mm	30.720
4-May-91	MP-6	60mm	1.050
4-May-91	MP-7	81mm	9.530
4-May-91	MP-8	81mm	17.854
1-Jun-91	MP-1	60mm	0.838
1-Jun-91	MP-3	60mm	1.800
1-Jun-91	MP-3	81mm	13.720
5-Jun-91	MP-1	107mm	19.210
6-Jun-91	MP-1	107mm	48.030
8-Jun-91	MP-1	60mm	2.013
17-Jun-91	MP-1	81mm	3.810
18-Jun-91	MP-1	81mm	14.090
18-Jun-91	MP-2	60mm	0.330
18-Jun-91	MP-3	107mm	9.260
18-Jun-91	MP-4	107mm	0.340
18-Jun-91	MP-4	107mm	34.310
18-Jun-91	MP-7	81mm	4.450
18-Jun-91	T-Range	81mm	2.750
19-Jun-91	IBC	60mm	1.940
19-Jun-91	IBC	81mm	0.320
19-Jun-91	MP-3	107mm	59.350
19-Jun-91	MP-6	107mm	109.450
19-Jun-91	MP-6	81mm	1.910
19-Jun-91	MP-7	107mm	37.740
19-Jun-91	MP-7	81mm	91.140
20-Jun-91	T-Range	81mm	16.040
21-Jun-91	MP-3	60mm	1.640
21-Jun-91	MP-3	81mm	13.200
22-Jun-91	MP-3	107mm	20.930
22-Jun-91	MP-3	81mm	12.920
22-Jun-91	MP-4	107mm	17.150
22-Jun-91	T-Range	81mm	11.500
23-Jun-91	MP-1	81mm	18.750
23-Jun-91	MP-2	81mm	3.180
23-Jun-91	MP-3	107mm	100.860
23-Jun-91	MP-4	81mm	57.910
23-Jun-91	T-Range	81mm	4.490
24-Jun-91	MP-1	81mm	3.180
24-Jun-91	MP-1	81mm	50.530
24-Jun-91	MP-3	107mm	134.290
15-Jul-91	IBC	60mm	1.500
17-Jul-91	MP-3	60mm	24.590
19-Jul-91	MP-1	60mm	0.300
19-Jul-91	MP-3	60mm	1.000
22-Jul-91	MP-1	81mm	1.800
23-Jul-91	MP-3	107mm	6.520
23-Jul-91	MP-4	81mm	43.130
24-Jul-91	IBC	81mm	50.660
24-Jul-91	MP-3	107mm	10.640
24-Jul-91	MP-7	107mm	2.740
25-Jul-91	MP-3	107mm	99.170
27-Jul-91	MP-1	81mm	49.490
29-Jul-91	IBC	81mm	4.450
29-Jul-91	MP-8	60mm	2.940
1-Aug-91	MP-1	60mm	0.830
7-Aug-91	MP-1	81mm	11.870
12-Aug-91	MP-1	81mm	12.280
7-Sep-91	MP-1	81mm	25.610
5-Oct-91	MP-1	107mm	13.723
5-Oct-91	MP-1	81mm	12.171
5-Oct-91	MP-3	107mm	3.360
5-Oct-91	MP-3	81mm	2.540
5-Oct-91	MP-4	81mm	6.360
5-Oct-91	MP-7	60mm	0.713
5-Oct-91	MP-9	81mm	5.080
19-Oct-91	MP-1	60mm	0.989
2-Nov-91	MP-1	60mm	1.250
2-Nov-91	MP-1	81mm	4.240
2-Nov-91	MP-3	60mm	0.488
2-Nov-91	MP-4	81mm	4.766
2-Nov-91	MP-5	81mm	0.110
2-Nov-91	MP-8	60mm	0.975
23-Nov-91	MP-4	81mm	5.300

Table C-14: M9 Propellant Burn Data for 1992

Date of Firing	Mortar Point	Mortar Type	Propellant Weight Burned (lbs)
3-Mar-92	MP-1	81mm	0.110
3-Mar-92	MP-3	60mm	0.050
3-Mar-92	MP-6	60mm	0.025
15-Mar-92	MP-3	81mm	9.530
21-Mar-92	MP-6	81mm	0.110
22-Mar-92	MP-5	81mm	3.810
22-Mar-92	MP-6	81mm	7.940
4-Apr-92	MP-1	81mm	4.240
4-Apr-92	MP-2	81mm	9.750
4-Apr-92	MP-3	81mm	1.800
4-Apr-92	MP-4	107mm	12.010
4-Apr-92	MP-5	60mm	0.625
4-Apr-92	MP-6	81mm	10.590
4-Apr-92	MP-7	60mm	0.800
5-Apr-92	MP-3	81mm	2.220
5-Apr-92	MP-4	107mm	5.150
5-Apr-92	MP-8	60mm	2.700
11-Apr-92	MP-1	81mm	11.020
11-Apr-92	MP-8	81mm	14.830
2-May-92	MP-1	81mm	7.690
2-May-92	MP-1	81mm	3.070
2-May-92	MP-2	107mm	27.790
2-May-92	MP-3	60mm	0.750
2-May-92	MP-4	107mm	0.340
2-May-92	MP-5	81mm	15.460
2-May-92	MP-6	60mm	1.610
2-May-92	MP-7	60mm	7.170
11-May-92	MP-8	81mm	13.770
16-May-92	MP-2	60mm	0.750
16-May-92	MP-4	81mm	12.980
26-May-92	MP-1	81mm	7.380
26-May-92	MP-2	81mm	6.570
26-May-92	MP-3	81mm	26.590
30-May-92	MP-3	81mm	26.400
6-Jun-92	MP-8	60mm	1.450
6-Jun-92	MP-8	81mm	2.000
13-Jun-92	MP-7	60mm	3.360
19-Jun-92	MP-8	81mm	11.120
27-Jun-92	MP-4	81mm	49.870
11-Jul-92	MP-3	81mm	13.990
27-Jul-92	MP-7	81mm	11.210
27-Jul-92	MP-8	81mm	2.430
24-Aug-92	MP-8	81mm	2.790
9-Sep-92	MP-8	60mm	6.860
10-Sep-92	MP-5	60mm	0.950
10-Sep-92	MP-6	81mm	7.080
10-Sep-92	MP-8	81mm	8.920
12-Sep-92	MP-1	81mm	10.800
3-Oct-92	MP-8	107mm	17.290
21-Oct-92	MP-8	60mm	3.070
21-Oct-92	MP-8	81mm	8.900
7-Nov-92	MP-2	60mm	1.390
7-Nov-92	MP-4	81mm	3.920
7-Nov-92	MP-6	60mm	0.760
7-Nov-92	MP-7	60mm	0.860

Table C-15: M9 Propellant Burn Data for 1993

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
1-Jan-93	MP-3	81mm	839	19.54
1-Jan-93	MP-4	81mm	60	0.28
6-Jan-93	MP-4	81mm	330	1.54
6-Jan-93	MP-4	81mm	2080	49.97
6-Jan-93	MP-5	60mm	554	3.46
6-Jan-93	MP-6	60mm	680	4.25
7-Jan-93	MP-5	60mm	454	2.84
7-Jan-93	MP-6	60mm	422	2.64
7-Jan-93	MP-8	81mm	515	4.34
31-Mar-93	MP-8	60mm	72	0.45
31-Mar-93	MP-8	81mm	375	7.94
3-Apr-93	MP-3	60mm	680	13.22
3-Apr-93	MP-4	60mm	88	0.6
3-Apr-93	MP-5	81mm	450	10.48
24-Apr-93	MP-2	81mm	197	0.46
24-Apr-93	MP-3	81mm	243	5.66
30-Apr-93	MP-5	81mm	756	17.6
1-May-93	MP-4	81mm	185	3.92
1-May-93	MP-6	107mm	3836	63.23
1-May-93	MP-8	81mm	630	13.35
2-May-93	MP-4	81mm	340	7.2
10-May-93	MP-8	60mm	200	1.26
10-May-93	MP-8	60mm	536	3.37
15-May-93	MP-3	60mm	680	12.84
15-May-93	MP-5	107mm	840	14.41
5-Jun-93	MP-3	60mm	590	7.33
5-Jun-93	MP-6	81mm	347	8.08
12-Jun-93	MP-3	107mm	2000	34.31
12-Jun-93	MP-7	60mm	186	1.17
22-Jun-93	MP-2	81mm	30	0.7
24-Jun-93	MP-1	81mm	516	12.02
24-Jun-93	MP-2	81mm	180	8.38
24-Jun-93	MP-3	107mm	320	20.59
25-Jun-93	MP-2	81mm	410	9.55
26-Jun-93	MP-2	81mm	727	16.93
26-Jun-93	MP-3	107mm	800	19.9
26-Jun-93	MP-8	81mm	750	20.97
27-Jun-93	MP-8	81mm	438	10.2
28-Jun-93	MP-3	107mm	846	14.41
28-Jun-93	MP-8	81mm	1253	29.81
30-Jun-93	MP-3	107mm	438	10.2
13-Jul-93	MP-8	81mm	156	3.63
16-Jul-93	MP-7	107mm	269	4.52
16-Jul-93	MP-8	81mm	195	9.65
16-Jul-93	MP-8	107mm	450	7.55
17-Jul-93	MP-4	107mm	1080	18.53
17-Jul-93	MP-4	107mm	540	9.26
17-Jul-93	MP-8	81mm	505	5.83
18-Jul-93	MP-4	107mm	2805	47.08
18-Jul-93	MP-4	81mm	505	10.7
18-Jul-93	MP-8	81mm	150	3.18
19-Jul-93	MP-1	107mm	480	10.29
19-Jul-93	MP-3	81mm	600	10.17
20-Jul-93	MP-1	107mm	660	11.32
20-Jul-93	MP-4	81mm	270	18.53
24-Jul-93	MP-8	81mm	576	13.41
28-Jul-93	MP-3	81mm	155	1.09
30-Jul-93	MP-1	60mm	20	0.41
30-Jul-93	MP-1	81mm	619	14.41
30-Jul-93	MP-3	60mm	24	0.46
31-Jul-93	MP-1	60mm	24	0.15
31-Jul-93	MP-1	81mm	42	0.7
31-Jul-93	MP-3	60mm	24	0.15
31-Jul-93	MP-3	81mm	30	0.7
1-Aug-93	MP-3	60mm	48	0.34
2-Aug-93	MP-3	60mm	48	0.34

Table C-16: M9 Propellant Burn Data for 1994

Date of Firing	Mortar Point	Mortar Type	Increments Burned	Propellant Weight Burned (lbs)
05-Feb-94	mp7	81mm	220	5.12
06-Feb-94	mp4	81mm	436	10.15
09-Apr-94	mp6	81mm	682	15.88
17-Apr-94	mp2	107mm	1666	27.88
30-Apr-94	mp3	81mm	360	8.38
14-May-94	mp3	81mm	294	6.85
14-May-94	mp4	81mm	294	6.85
14-May-94	mp1	81mm	294	6.85
14-May-94		81mm	7	0.16
14-May-94		81mm	126	2.93
14-May-94		81mm	119	2.77
14-May-94		81mm	7	0.16
14-May-94		81mm	119	2.77
14-May-94		81mm	84	1.96
14-May-94		81mm	114	2.65
14-May-94		81mm	84	1.96
14-May-94		81mm	186	4.33
14-May-94		81mm	140	3.26
14-May-94		81mm	5	0.12
14-May-94		81mm	5	0.12
14-May-94		81mm	20	0.47
14-May-94		81mm	60	1.40
14-May-94		81mm	60	1.40
14-May-94		81mm	30	0.70
14-May-94		81mm	60	1.40
15-May-94		81mm	175	4.08
15-May-94		81mm	21	0.49
15-May-94		81mm	54	1.26
05-Jun-94	mp3	81mm	242	5.64
20-Jun-94	mp1	107mm	272.375	4.56
20-Jun-94	mp3	81mm	20	0.47
20-Jun-94	mp4	81mm	186	4.33
21-Jun-94	mp2	107mm	398.875	6.68
21-Jun-94	mp1	107mm	408	6.83
21-Jun-94	mp3	81mm	119	2.77
21-Jun-94	mp1	81mm	60	1.40
22-Jun-94	mp4	81mm	136	3.17
24-Jun-94	mp3	81mm	54	1.26
25-Jun-94	mp6	81mm	38	0.88
25-Jun-94	mp4	81mm	29	0.68
25-Jun-94	mp4	81mm	2	0.05
26-Jun-94	mp1	107mm	397.125	6.65
26-Jun-94	mp4	81mm	100	2.33
26-Jun-94	mp4	81mm	40	0.93
26-Jun-94	mp6	81mm	40	0.93
26-Jun-94	mp6	81mm	102	2.38
11-Jul-94	mp6	81mm	267	6.22
24-Aug-94	mp8	60mm	60	0.38
24-Aug-94	mp8	81mm	183	4.26
30-Aug-94	mp8	60mm	56	0.35
30-Aug-94	mp8	81mm	54	1.26
09-Sep-94	mp6	81mm	525	12.23
10-Sep-94	mp7	81mm	352	8.20
10-Sep-94	mp3	81mm	377	8.78
10-Sep-94	mp8	81mm	610	14.20
11-Sep-94	mp7	81mm	252	5.87
12-Sep-94	mp3	107mm	481.875	8.06
08-Nov-94	mp8	60mm	340	2.13
09-Nov-94	mp8	81mm	217	5.05
10-Nov-94	mp8	81mm	325	7.57
20-Nov-94	mp3	81mm	388	9.03

Appendix D

CHEMICAL AND PHYSICAL PARAMETERS

Chemical Name	MW (g)	Da (cm2/sec)	Ref	Dw (cm2/sec)	Ref	Henry's Constant atm-m3/mol	Ref
Aluminum	2.7E+1	4.16E-1	7	3.81E-5	7	NA	
Cadmium	1.12E+2	NA	5	8.0E-6	5	NA	
Calcium	4.01E+1	1.62E-1	8	1.88E-5	8	NA	
Copper	6.40E+1	3.68E-1	7	4.65E-5	7	NA	
Lead	2.07E+2	NA	5	8.0E-6	6	NA	
Mercury	2.01E+2	5.1E-2	5	6.3E-6	5	7.1E-10	10
Potassium	3.91E+1	1.65E-1	8	1.91E-5	8	NA	
Sodium	2.3E+1	2.35E-1	8	2.72E-5	8	NA	
Titanium	4.79E+1	1.44E-1	8	1.67E-5	8	NA	
Zinc	6.50E+1	1.18E-1	8	1.36E-5	8	NA	
Acenaphthylene	1.52E+2	4.21E-2	11	7.69E-6	11	1.13E-5	1
Acetophenone	1.20E+2	6.0E-2	5	8.7E-6	5	1.1E-5	5
4-Aminobiphenyl	1.69E+2	6.21E-2	8	7.20E-6	8	3.89E-10	3
Benzo(a)anthracene	2.28E+2	6.1E-2	5	9.0E-6	5	3.4E-6	5
Benzo(a)pyrene	2.52E+2	4.3E-2	5	9.0E-6	5	1.1E-6	5
Benzo(b)fluoranthene	2.52E+2	2.3E-2	5	6.4E-6	5	1.1E-4	5
Benzo(ghi)perylene	2.76E+2	4.48E-2	8	5.19E-6	8	1.60E-6	1
Benzoic Acid	1.22E+2	5.36E-2	11	7.97E-6	11	1.08E-7	1
Benzonitrile	1.03E+2	8.65E-2	8	1.0E-5	8	5.21E-5	1
Bis(2Ethylhexyl)phthalate	3.91E+2	3.5E-2	5	3.7E-6	5	1.0E-4	10
Butyl benzyl phthalate	3.12E+2	1.7E-2	5	4.9E-6	5	1.3E-6	5
Di-n-butyl phthalate	2.78E+2	2.6E-2	5	6.4E-6	5	4.5E-5	5
Di-n-octyl phthalate	8.0E-2	1.5E-2	5	3.6E-6	5	2.20E-4	10
Dibenzofuran	1.68E+2	6.24E-2	8	7.23E-6	8	1.30E-4	1
Diethyl phthalate	2.22E+2	2.5E-2	5	6.34E-6	5	4.5E-7	5
Dimethyl phthalate	1.94E+2	6.7E-2	5	6.3E-6	5	1.1E-7	5
2,4- Dimethylphenol	1.22E+2	8.0E-2	5	8.0E-6	5	3.3E-6	5
2,4-Dinitrotoluene	1.82E+2	2.0E-1	5	7.10E-6	5	9.3E-8	5
Diphenylamine	1.69E+2	6.8E-2	5	6.3E-6	5	5.0E-7	5
Fluoranthene	2.02E+2	3.02E-2	5	6.4E-6	5	1.6E-5	5
HMX	2.96E+2	4.28E-2	8	4.95E-6	8	3.08E-11	6
2-Methylnapthalene	2.36E+2	4.98E-2	8	5.75E-6	8	5.18E-4	1
N-Nitrosodiphenylamine	1.98E+2	3.12E-2	11	6.35E-6	11	6.40E-4	1
Naphthalene	1.28E+2	5.9E-2	5	7.50E-6	5	4.83E-4	5
2-Nitrodiphenylamine	2.14E+2	5.31E-2	8	6.15E-6	8	NA	

Chemical Name	MW (g)	Da (cm2/sec)	Ref	Dw (cm2/sec)	Ref	Henry's Constant atm-m3/mol	Ref
2-Nitrophenol	1.39E+2	7.08E-2	8	8.20E-6	8	3.50E-6	1
4-Nitrophenol	1.39E+2	7.08E-2	8	8.20E-6	8	3.0E-5	3
Phenacetin	1.79E+2	5.98E-2	8	6.93E-6	8	1.40E-6	1
Phenanthrene	1.78E+2	8.90E-2	7	7.48E-6	7	1.24E-4	1
Phenol	9.41E+1	8.90E-2	5	9.1E-6	5	4.0E-7	5
Pyrene	2.02E+2	8.43E-2	7	7.24E-6	7	5.42E-5	1
RDX	2.22E+2	9.31E-2	7	8.53E-6	7	6.30E-8	1
1,2,4-Trichlorobenzene	1.81E+2	3.0E-2	5	8.2E-8	5	1.4E-3	5
2,4,6-Trinitrotoluene	2.27E+2	5.11E-2	8	5.91E-6	8	4.57E-7	1
Benzene	7.81E+1	8.80E-2	5	9.80E-6	5	5.60E-3	5
Carbon Tetrachloride	1.54E+2	7.80E-2	5	8.80E-6	5	3.0E-2	5
Ethylbenzene	1.06E+2	7.50E-2	5	7.80E-6	5	7.9E-3	5
Methane	1.60E+1	2.99E-1	8	3.46E-5	8	6.57E-1	1
n-Propylbenzene	1.20E+2	1.02E-1	7	7.84E-6	7	1.05E-2	1
Styrene	1.04E+2	1.15E-1	5	8.0E-6	5	2.8E-3	5
Toluene	9.21E+1	8.70E-2	5	8.60E-6	5	6.6E-3	5
o-Xylene	101E+2	8.70E-2	5	1.0E-5	5	5.2E-3	5
m&p-Xylene	101E+2	7.50E-2	5	9.3E-6	5	6.0E-3	5
Hydrogen Chloride	3.65E+1	1.73E-1	8	NA	8	NA	5
Hydrogen Cyanide	2.70E+1	2.11E-1	8	2.44E-5	8	1.33E-4	1

Chemical Name	ksg (yr^{-1})	Ref	Kd_s (mL/g or L/kg)	Ref	Kdsw (L/kg)	Ref	Kdbs (L/kg)	Ref
Aluminum	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Cadmium	NA		1.6E+2	10	1.6E+2	10	10	#
Calcium	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Copper	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Lead	NA		8.8E+4	4	8.8E+4	#	8.8E+4	#
Mercury	NA	10	5.7E+4	10	9.5E+4	10	1.6E+5	10
Potassium	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Sodium	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Titanium	NA		1.6E+2	*	1.6E+2	#	1.6E+2	#
Zinc	NA		6.2E+1	12	6.2E+1	#	6.2E+1	#
Acenaphthylene	NA		7.24E+1	8	5.43E+2	8	2.9E+2	8
Acetophenone	NA		2.34E-1	8	1.76E0	8	9.38E-1	8
4-Aminobiphenyl	NA		3.89E0	8	2.92E+1	8	1.56E+1	8
Benzo(a)anthracene	3.72E-1	2	2.51E+3	8	1.95E+4	8	1.04E+4	8
Benzo(a)pyrene	4.77E-1	2	7.10E+3	8	5.33E+4	8	2.84E+4	8
Benzo(b)fluoranthene	4.15E-1	2	8.36E0	8	6.27E+4	8	3.34E+4	8
Benzo(ghi)perylene	NA		2.34E-4	8	1.76E+5	8	9.38E+4	8
Benzoic Acid	NA		4.57E-1	8	3.43E0	8	1.83	8
Benzonitrile	NA		2.24E-1	8	1.68E0	8	8.95E-1	8
Bis(2-Ethylhexyl)phthalate	NA		2.80E+5	10	2.10E+6	10	1.12E+6	10
Butyl benzyl phthalate	NA		3.63E+2	8	2.72E+3	8	1.45E-3	8
Di-n-butyl phthalate	NA		4.90E+2	8	3.67E+3	8	1.96E-3	8
Di-n-octyl phthalate	NA		2.8E+5	10	2.10E+6	10	1.10E+6	10
Dibenzofuran	NA		8.13E+1	8	6.10E+2	8	3.25E+2	8
Diethyl phthalate	NA		1.82	8	1.36E+1	8	7.28	8
Dimethyl phthalate	NA		8.13E-1	8	6.10E0	8	3.25	8
2,4- Dimethylphenol	NA		3.63	8	2.72E+1	8	1.45E+1	8
2,4-Dinitrotoluene	NA		8.70E-1	9	6.50	9	3.50	9
Diphenylamine	NA		1.02E+1	8	7.67E+1	8	4.09E+1	8
Fluoranthene	NA		4.90E+2	8	3.67E+3	8	1.96E-3	8
HMX	NA		1.12E-2	8	8.42E-2	8	4.49E-2	8
2-Methylnapthalene	NA		4.57E+1	8	3.43E+2	8	1.83E+2	8
N-Nitrosodiphenylamine	NA		8.32	8	6.24E+1	8	3.33E+1	8
Naphthalene	NA		1.23E1	8	9.23E+1	8	4.92E+1	8
2-Nitrodiphenylamine	NA		NA		NA		NA	
2-Nitrophenol	NA		3.80E-1	8	2.85E0	8	1.52	8
4-Nitrophenol	NA		5.01E-1	8	3.76E0	8	2.0	8
Phenacetin	NA		2.34E-1	8	1.76E0	8	9.38E-1	8

Chemical Name	ksg (yr^{-1})	Ref	Kd_s (mL/g or L/kg)	Ref	Kdsw (L/kg)	Ref	Kdbs (L/kg)	Ref
Phenanthrene	NA		2.29E+2	8	1.72E+3	8	9.16E+2	8
Phenol	NA		1.78E-1	8	1.33	8	7.11E-1	8
Pyrene	NA		4.68E+2	8	3.51E+3	8	1.87E+3	8
RDX	NA		4.47E-2	8	3.43E-1	8	1.83E-1	8
1,2,4-Trichlorobenzene	NA		6.46E+1	8	4.84E+2	8	2.58E+2	8
2,4,6-Trinitrotoluene	NA		2.27E0	8	1.70E+1	8	9.08	8
Benzene	NA		8.32E-1	8	6.24E0	8	3.33	8
Carbon Tetrachloride	NA		4.17	8	3.13E-1	8	1.67E+1	8
Ethylbenzene	NA		8.71	8	6.53E+1	8	5.48E+1	8
Methane	NA		7.59E-2	8	5.69E-1	8	3.03E-1	8
n-Propylbenzene	NA		2.29E+1	8	1.72E+2	8	9.16E+1	8
Styrene	NA		5.50	8	4.13E+1	8	2.20E+1	8
Toluene	NA		1.6	8	1.20E+1	8	6.40	8
o-Xylene	NA		8.13	8	6.10E+1	8	3.25E+1	8
m&p-Xylene	NA		8.71	8	6.53+1	8	3.48E+1	8
Hydrogen Chloride	NA		6.17E-3	8	4.62E-2	8	2.47E-2	8
Hydrogen Cyanide	NA		3.47E-3	8	2.60E-2	8	1.39E-2	8

Chemical Name	Bv [ug COC/ g DW]/[ug COC/ g air]	Ref	Br [ug/g DW]/[ug/g soil]	Ref	RCF [ug COC/g FW]/ [ug COC/ml]	Ref	Fish BCF (L/kg)	Ref	Fish BAF (L/kg)	Ref
Aluminum	NA		NA		NA		9.12E-1	*	NA	
Cadmium	NA	5	3.6E-1	5	3.20E-2	10	6.40E+1	10	NA	10
Calcium	NA		NA		NA		9.12E-1	*	NA	
Copper	NA		NA		NA		9.12E-1	*	NA	
Lead	NA		1.3E-5		NA		NA		8.0	4
Mercury	2.3E+4	10	9.0E-1		7.0E-3	10	NA	10	1.3E+5	10
Potassium	NA		NA		NA		9.12E-1	*	NA	
Sodium	NA		NA		NA		9.12E-1	*	NA	
Titanium	NA		NA		NA		9.12E-1	*	NA	
Zinc	NA	4	2.5E-1	4	NA	4	8.8E+1	5	NA	4
Acenaphthylene	2.69E+2	8	1.72E-1	8	4.19E+1	8	NA	8	3.5E+3	8
Acetophenone	2.9E+1	5	4.4	5	1.4	5	5.2	5	NA	5
4-Aminobiphenyl	3.48E+5	8	9.32E-1	8	5.15E0	8	6.49E+1	8	NA	8
Benzo(a)anthracene	2.7E+4	5	2.0E-2	5	7.4	5	NA	5	4.0E+1	5
Benzo(a)pyrene	4.7E+4	5	1.11E-2	5	1.58E+3	5	NA	5	1.0E+3	5
Benzo(b)fluoranthene	5.1E+3	5	1.0E-2	5	1.80E+3	5	NA	5	1.0E+3	5
Benzo(ghi)perylene	8.97E+5	8	6.09E-3	8	3.52E+3	8	6.28E+4	8	NA	8
Benzoic Acid	1.28E+2	8	3.21	8	1.65	8	1.19E+1	8	NA	8
Benzonitrile	1.24E-1	8	4.86	8	1.30	8	6.80	8	NA	8
Bis(2Ethylhexyl) phthalate	1.45E+5	10	2.3E-3	5	1.80E+4	10	NA	10	1.2E+2	10
Butyl benzyl phthalate	6.3E+5	5	6.2E-2	5	1.6E+2	5	NA	5	4.6E+3	5
Di-n-butyl phthalate	4.8E+8	5	8.4E-2	5	1.1E+2	5	NA	5	3.1E+1	5
Di-n-octyl phthalate	6.20E+4	10	8.5E-4	5	1.80E+4	10	NA	5	1.20E+2	5
Dibenzofuran	2.65E+1	8	1.61E-1	8	4.57E+1	8	NA	8	3.92E+3	8
Diethyl phthalate	5.7E+3	5	1.4E0	5	3.4E0	5	3.60E+1	5	NA	5
Dimethyl phthalate	2.5E+3	5	4.8	5	1.3	5	6.0	5	NA	5
2,4- Dimethylphenol	2.83E+2	8	9.70E-1	8	9.5	5	3.1E+1	5	NA	5
2,4-Dinitrotoluene	1.50E+2	9	2.7E0	9	1.90E0	9	3.20E0	9	NA	9
Diphenylamine	5.7E+4	5	3.8E-1	5	1.5E+1	5	9.5E+1	5	NA	5
Fluoranthene	3.5E+3	5	4.3E-2	5	2.7E+2	5	NA	5	9.6E+1	5
HMX	8.66E+3	8	2.74E1	8	8.68E-1	8	6.39E-1	8	NA	8
2-Methylnapthalene	3.60	8	2.24E-1	8	2.96E+1	8	4.54E+2	8	NA	8
N-Nitrosodiphenylamine	4.75E-1	8	6.01E-1	8	8.58E0	8	1.18E+2	8	NA	8
Naphthalene	4.4E+1	5	4.4E-1	5	1.2E+1	5	7.2E+1	5	NA	5
2-Nitrodiphenylamine	NA		NA		NA		NA		NA	
2-Nitrophenol	3.25	8	3.58	8	1.54	8	1.03E+1	8	NA	8

Chemical Name	Bv [ug COC/ g DW]/[ug COC/ g air]	Ref	Br [ug/g DW]/[ug/g soil]	Ref	RCF [ug COC/g FW]/ [ug COC/ml]	Ref	Fish BCF (L/kg)	Ref	Fish BAF (L/kg)	Ref
4-Nitrophenol	5.08E-1	8	3.05	8	1.71	8	1.28E+1	8	NA	8
Phenacetin	4.85	8	4.73	8	1.32	8	7.05	8	NA	8
Phenanthrene	8.37E+1	8	8.84E-2	8	1.01E+2	8	NA	8	1.18E+4	8
Phenol	5.3E+2	5	5.4	5	1.2	5	1.7E+3	5	NA	5
Pyrene	1.58E+6	8	4.09E+2	8	5.85E-2	8	NA	8	3.13E+4	8
RDX	1.08E+3	8	1.22E+1	8	9.61E-1	8	NA	8	9.69E0	8
1,2,4-Trichlorobenzene	7.3E+1	5	1.9E-1	5	3.8E+1	5	NA	5	5.3E+2	5
2,4,6-Trinitrotoluene	1.56E+1	8	4.60	8	1.34	8	7.13	8	NA	8
Benzene	1.9E-1	5	2.3	5	2.1	5	4.2	5	NA	5
Carbon Tetrachloride	1.5E-1	5	1.0	5	4.6	5	1.7E+1	5	NA	5
Ethylbenzene	1.6	5	5.9E-1	5	8.7	5	7.9E+1	5	NA	5
Methane	3.11E-6	8	9.08	8	1.03	8	2.89	8	NA	8
n-Propylbenzene	8.51E-2	8	3.35E-1	8	1.78E+1	8	2.63E+2	8	NA	8
Styrene	2.7	5	7.7E-1	5	6.4	5	5.5E+1	5	NA	5
Toluene	7.1E-1	5	1.0	5	4.8	5	4.8E+1	5	NA	5
o-Xylene	5.80E-2	5	6.00E-1	5	8.6	5	NA	5	NA	5
m&p-Xylene	2.2	5	5.7E-1	5	9.2	5	8.4E+1	5	NA	5
Hydrogen Chloride	NA	5	NA	8	NA	8	NA	8	NA	8
Hydrogen Cyanide	NA	8	5.40E+1	8	8.39E-1	8	9.12E-1	8	NA	8

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Equations and Definitions

1) MW = molecular weight

2) D_a = diffusivity of substance in air = $1.9/MW^{2/3}$ (Equation 9-31; ref 7)

3) D_w = diffusivity of substance in water = $(22 \times 10^{-5})/MW^{2/3}$ (Equation 9-30; ref 7)

4) Koc = organic carbon partition coefficient = $10^{\log Kow - 0.21}$ (Equation 9-50; ref 7)

5) Kow = octanol/water partition coefficient

6) H = Henry's Law constant

7) Fw = fraction of wet deposition that adheres to plant surfaces

8) ksg = soil loss due to degradation

9) Kd_s = soil-water partition coefficient = Koc x OCs, where OCs = organic carbon content (Equation 9-49; ref 7)

10) Kd_{sw} = suspended sediment-surface water partition coefficient = Koc x OCsw (Equation 9-49; ref 7)

11) Kd_{bs} = bottom sediment-sediment pore water partition coefficient = Koc x OCsb (Equation 9-49; ref 7)

12) Bv = air to plant biotransfer factor = (1.2 x Bvol)/(0.15 x 770 x 40) (USEPA 1993a) Bvol = Bacci volumetric air-to-leaf biotransfer factor = $10^{1.588-0.578 \log Kow}$ (Equation 5-3; ref 7)

13) RCF = ratio of substance concentration in the roots to concentration in soil pore water = $10^{0.77 \log Kow-1.52}$ (Equation 5-3; ref 7)

14) Br = plant-soil bioconcentration factor = $10^{1.588-0.578 \log Kow}$ (Equation 5-3; ref 7)

15) BCF = fish bioconcentration factor = $10^{0.79 \log Kow-0.40}$ (40 CFR 132, Appendix B, April 16, 1993)

16) BAF = fish bioaccumulation factor = BCF x 5.0 x FCM (40 CFR 132, Appendix B, April 16, 1993)

Footnotes:

FCM = Food Chain Multiplier

* The Kd_s, Kd_{sw} and Kd_{bs} value for cadmium was also used for calcium, copper, potassium, sodium, and titanium as this information was not available

= Kd_{sw} and Kd_{sb} values for metals were set equal to Kd_s. For organics, the Kd values for soil and suspended sediments differs due to differing level of organic carbon in soil versus suspended sediments. However metals are not thought to be affected by organic carbon; therefore the KD values are the same.

Note : The Fw value for all COCs was .6

Appendix E

TOXICOLOGICAL DATA

Chemical Name	Cancer Slope Factor-Ingestion (per mg/kg/day)	Cancer Slope Factor-Inhalation (per mg/kg/day)	Unit Risk Factor (UR) (per ug/m^3)	Reference Dose (RfD) (mg/kg/day)	Reference Concentration (RfC) (mg/m^3)
Aluminum	NA	NA	NA	1.0 (3)	3.50E-3 (3)
Cadmium	NA	6.3 (3)	1.8E-3	5.0E-4 (4)	2.0E-4 (3)
Calcium	NA	NA	NA	NA	NA
Copper	NA	NA	NA	4.0E-2 (3)	1.44E-1 (3)!
Lead	NA	NA	NA	NA	NA
Mercury	NA	NA	NA	1.0E-4 (4)	3.0E-4 (4)
Potassium	NA	NA	NA	NA	NA
Sodium	NA	NA	NA	NA	NA
Titanium	NA	NA	NA	4.0 (3)	3.01E-2 (3)
Zinc	NA	NA	NA	3.0E-1 (4)	1.05 (3)!
Acenaphthylene	NA	NA	NA	NA	NA
Acetophenone	NA	NA	NA	1.0E-1 (4)	2.0E-5 (3)
4-Aminobiphenyl	NA	NA	NA	NA	NA
Benzo(a)anthracene	1.10 (1)	6.0 #	1.7E-3	NA	NA
Benzo(a)pyrene	7.3 (4)	6.0 (1)	1.7E-3	NA	NA
Benzo(b)fluoranthene	1.2 (1)	6.0 #	1.7E-3	NA	NA
Benzo(ghi)perylene	NA	NA	NA	NA	NA
Benzoic Acid	NA	NA	NA	4.0 (4)	1.47E1 (3)!
Benzonitrile	NA	NA	NA	NA	NA
Bis(2Ethylhexyl) phthalate	1.40E-2 (4)	1.40E-2 (3)	NA	2.0E-2 (4)	NA
Butyl benzyl phthalate	NA	NA	NA	2.0E-1 (4)	7.0E-1 (3)!
Di-n-butyl phthalate	NA	NA	NA	1.0E-1 (4)	3.55E-1 (3)!
Di-n-octyl phthalate	1.40E-2 *	1.4E-2 *	NA	2.0E-2 *	NA
Dibenzofuran	NA	NA	NA	4.0E-3 (3)	1.44E-2 (3)!
Diethyl phthalate	NA	NA	NA	8.0E-1 (4)	2.8E0 (3)!
Dimethyl phthalate	NA	NA	NA	1.0E1 (3)	3.55E1 (3)!
2,4- Dimethylphenol	NA	NA	NA	2.0E-2 (4)	7.0E-2 (3)!
2,4-Dinitrotoluene	6.8E-1 (2)	NA	NA	2.0E-3 (4)	7.0E-3 (3)!
Diphenylamine	NA	NA	NA	2.5E-2 (4)	8.75E-2 (3)!
Fluoranthene	NA	NA	NA	4.0E-2 (4)	1.44E-1 (3)!
HMX	NA	NA	NA	5.0E-2 (4)	1.73E-1 (3)!
2-Methylnapthalene	NA	NA	NA	4.0E-2 (3)	1.44E-1 (3)!
N-nitrosodiphenylamine	4.9E-3 (4)	NA	NA	NA	NA
Naphthalene	NA	NA	NA	4.0E-2 (3)	1.44E-1(3)!
2-Nitrodiphenylamine	NA	NA	NA	NA	NA

Chemical Name	Cancer Slope Factor-Ingestion (per mg/kg/day)	Cancer Slope Factor-Inhalation (per mg/kg/day)	Unit Risk Factor (UR) (per ug/m^3)	Reference Dose (RfD) (mg/kg/day)	Reference Concentration (RfC) (mg/m^3)
4-Nitrophenol	NA	NA	NA	8.0E-3 (3)	2.8E-2 (3)!
Phenacetin	NA	NA	NA	NA	NA
Phenanthrene	NA	NA	NA	NA	NA
Phenol	NA	NA	NA	6.0E-1 (4)	2.10 (3)!
Pyrene	NA	NA	NA	3.0E-2 (4)	1.05E-1 (3)!
RDX	1.1E-1 (4)	NA	NA	3.0E-3 (4)	NA
1,2,4-Trichlorobenzene	NA	NA	NA	1.0E-2 (4)	2.0E-1(3)
2,4,6-Trinitrotoluene	3.0E-2 (4)	NA	NA	5.0E-4 (1)	NA
Benzene	2.9E-3 (4)	2.9E-2 (3)	8.3E-6 (4)	3.0E-3 (3)	5.98E-3 (3)
Carbon Tetrachloride	1.30E-1 (4)	5.25E-2 (3)	1.5E-5 (4)	7.0E-4 (4)	2.0E-3 (3)
Ethylbenzene	NA	NA	NA	1.0E-1 (4)	1.0E0 (4)
Methane	NA	NA	NA	NA	NA
n-Propylbenzene	NA	NA	NA	1.0E-2 (3)	3.55E-2 (3)!
Styrene	NA	NA	NA	2.0E-1 (4)	1.0 (4)
Toluene	NA	NA	NA	2.0E-1 (4)	4.0E-1 (4)
o-Xylene	NA	NA	NA	2.0E0 (4)	7.0 (3)!
m&p-Xylene	NA	NA	NA	2.0E0 (4)	7.0 (3)!
Hydrogen Chloride	NA	NA	NA	3.0E-4 (1)	2.0E-2 (4)
Hydrogen Cyanide	NA	NA	NA	2.0E-2 (4)	3.0E-3 (4)

Notes:
( ) Reference numbers given in parentheses
* = Indicates value based on structural similarity to bis(2-ethylhexyl)phthalate
** = Indicates value based on structural similarity to 4-nitrophenol
# = Indicates toxicity value set the same as the value for benzo(a)pyrene
! = Indicates value determined from the Region III RBC table from ambient air values, which may be based on oral toxicity references.

REFERENCES FOR APPENDIX E

1. Research Triangle Institute. 1997. *North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units*. State of North Carolina Division of Waste Management, Research Triangle Park, North Carolina.

2. USEPA. 1994b. *Revised Draft of Risk Assessment Implementation Guidance for Hazardous Waste Combustion Facilities* which includes *Risk Assessment Implementation Guidance for Performing Screening Level Risk Analyses at Combustion Facilities*

Burning Hazardous Wastes. Revised Draft. Office of Solid Waste and Emergency Response. Memorandum from Michael H. Shapiro, Director, USEPA to: Waste Management Division Directors, Regions I-X.

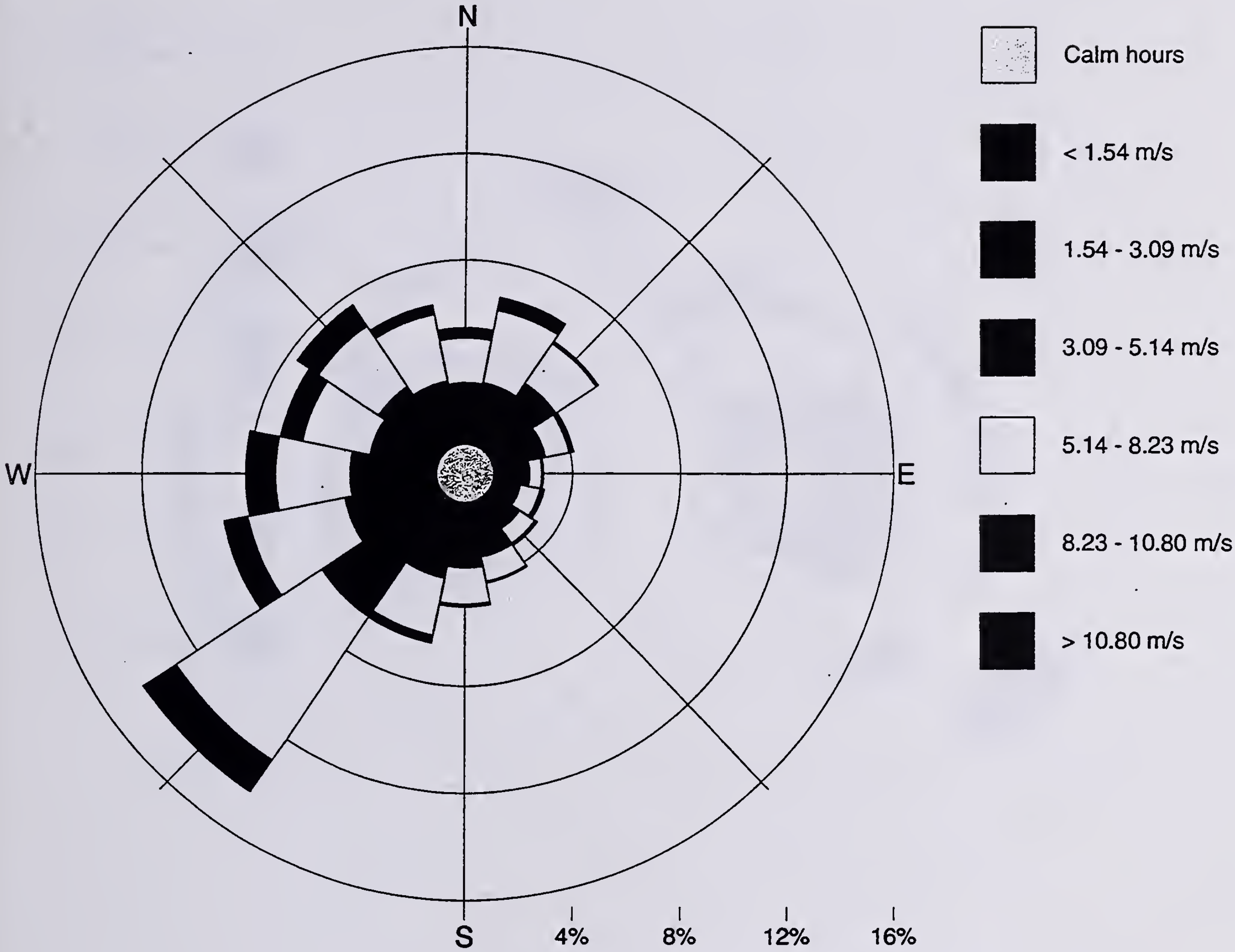
3. USEPA. 1997b. *Risk-Based Concentration Table.* Region III, Superfund Technical Support Section. Philadelphia, Pennsylvania.

4. USEPA, 1998. Integrated Risk Information System (IRIS) Database. Washington D.C.

Appendix F

METEOROLOGICAL WINDROSES

Windrose - mmrmet85.asc



Year: 1985

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)

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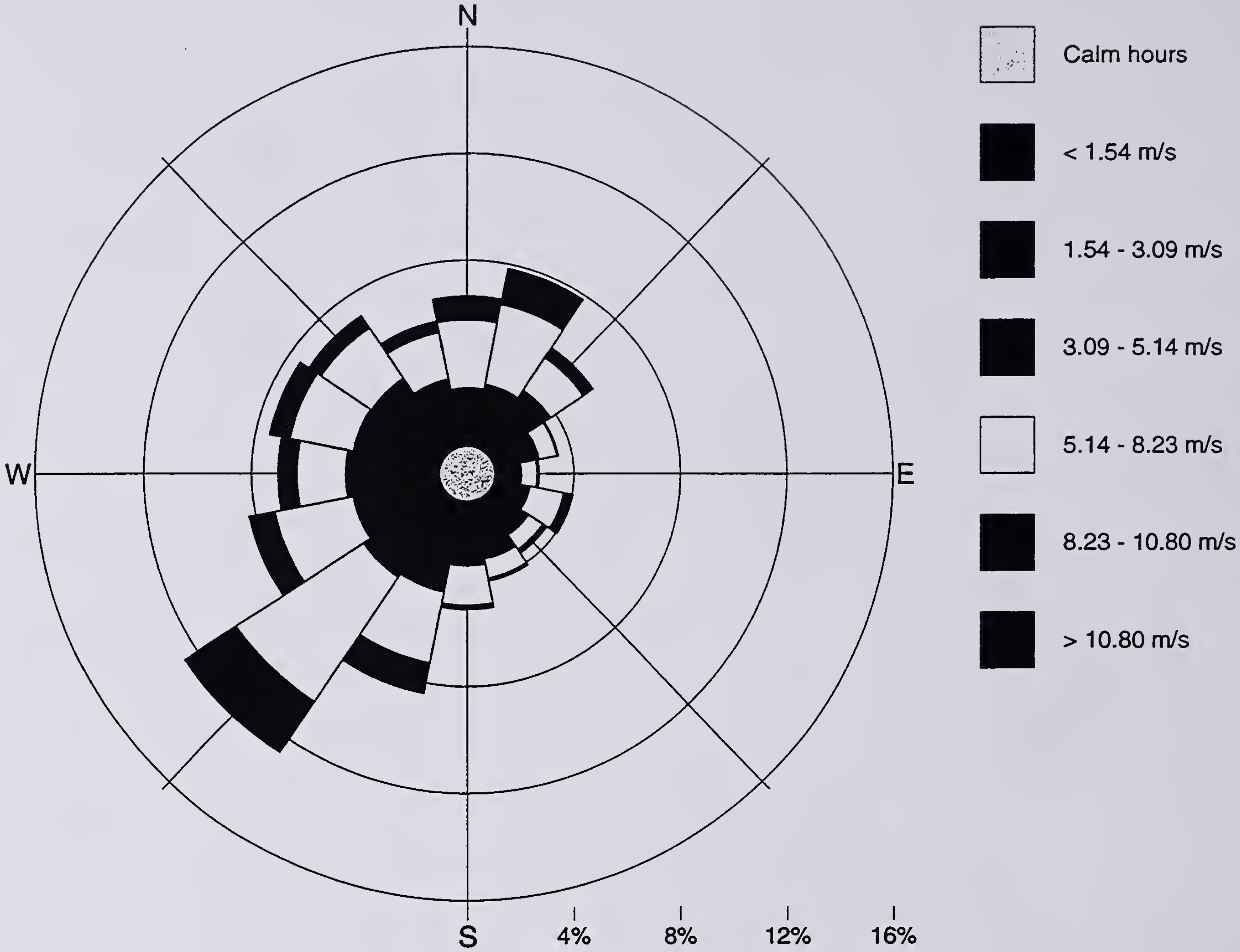
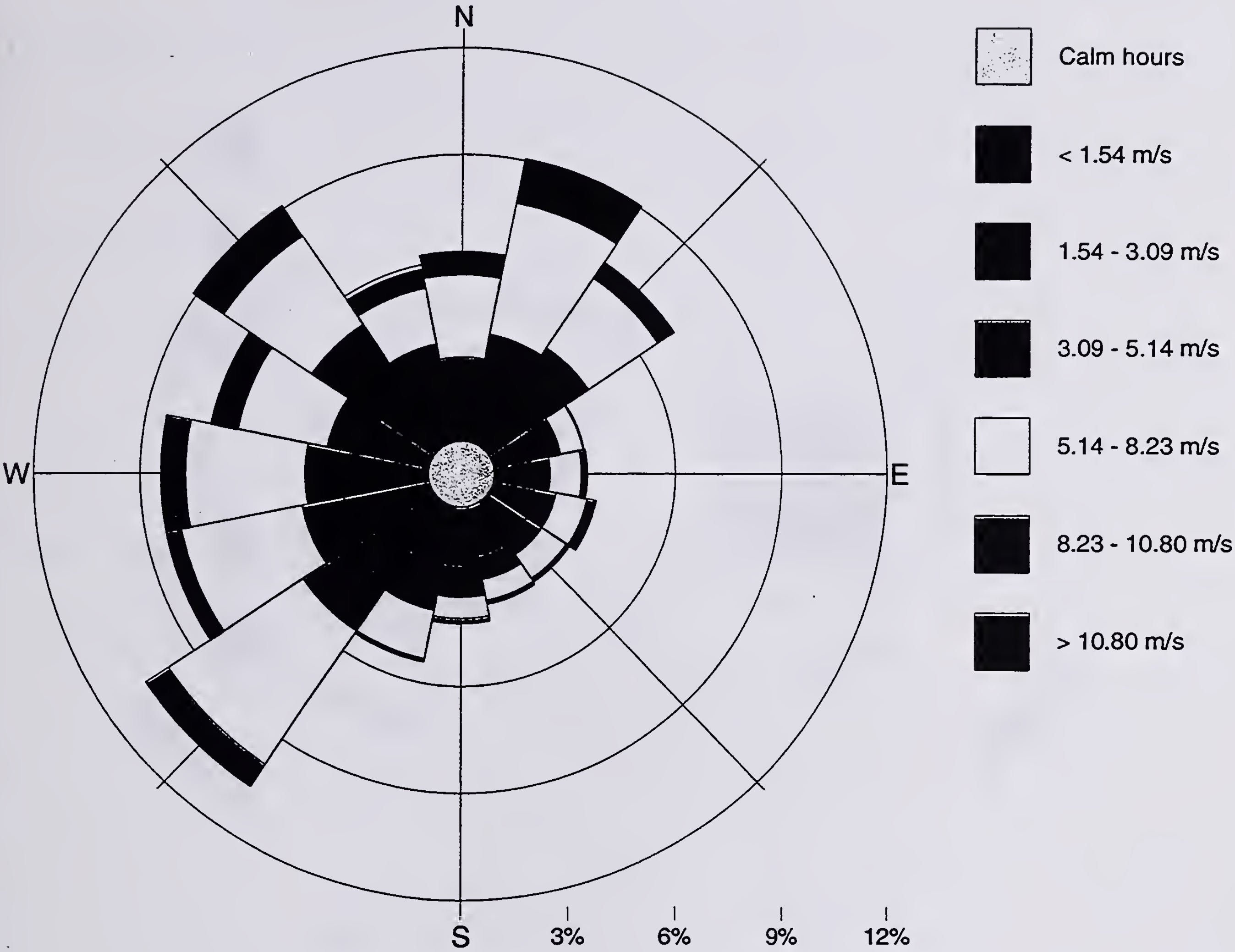


Year: 1986

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)

Windrose - mmrmet87.asc



Year: 1987

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14735 (Albany, NY)

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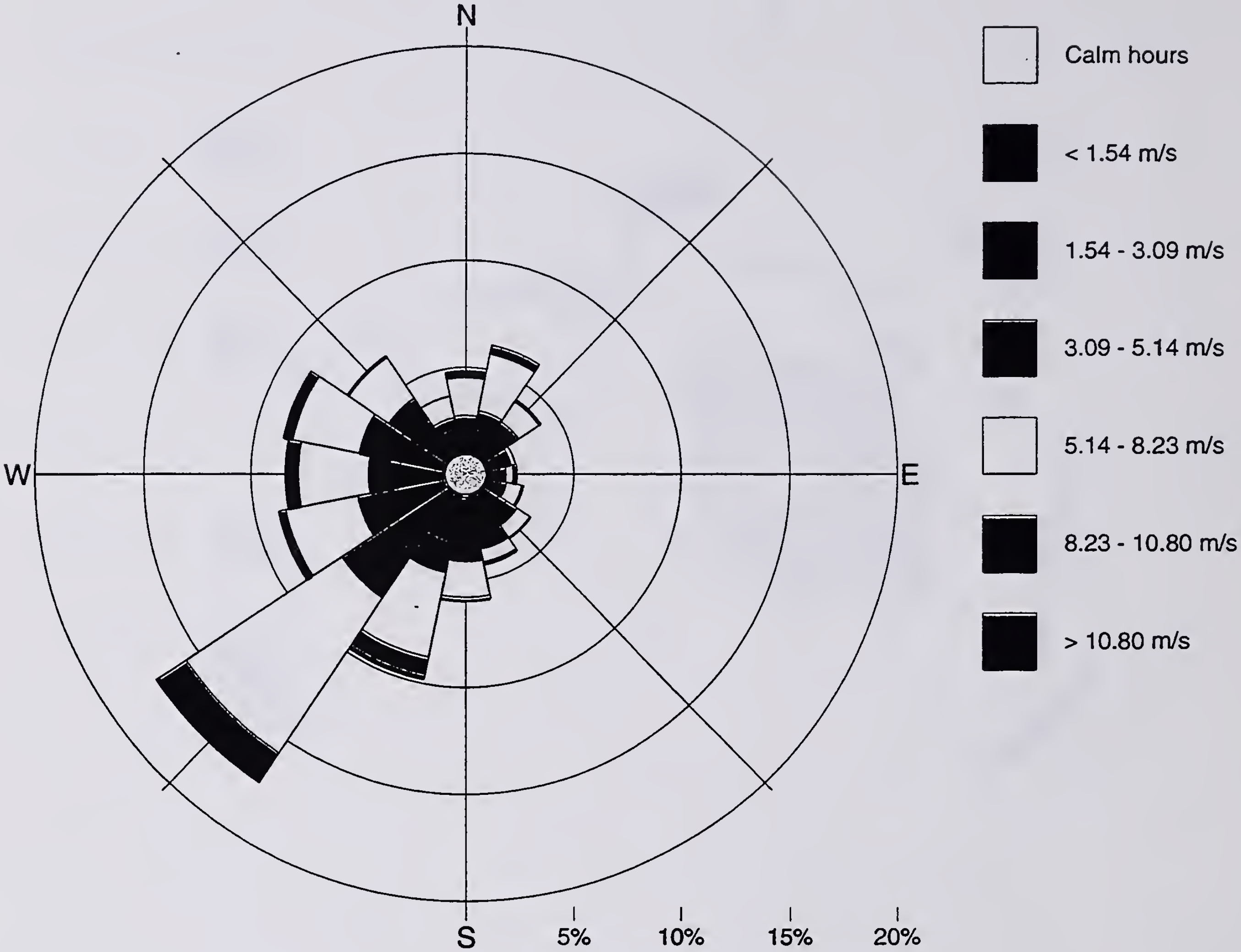
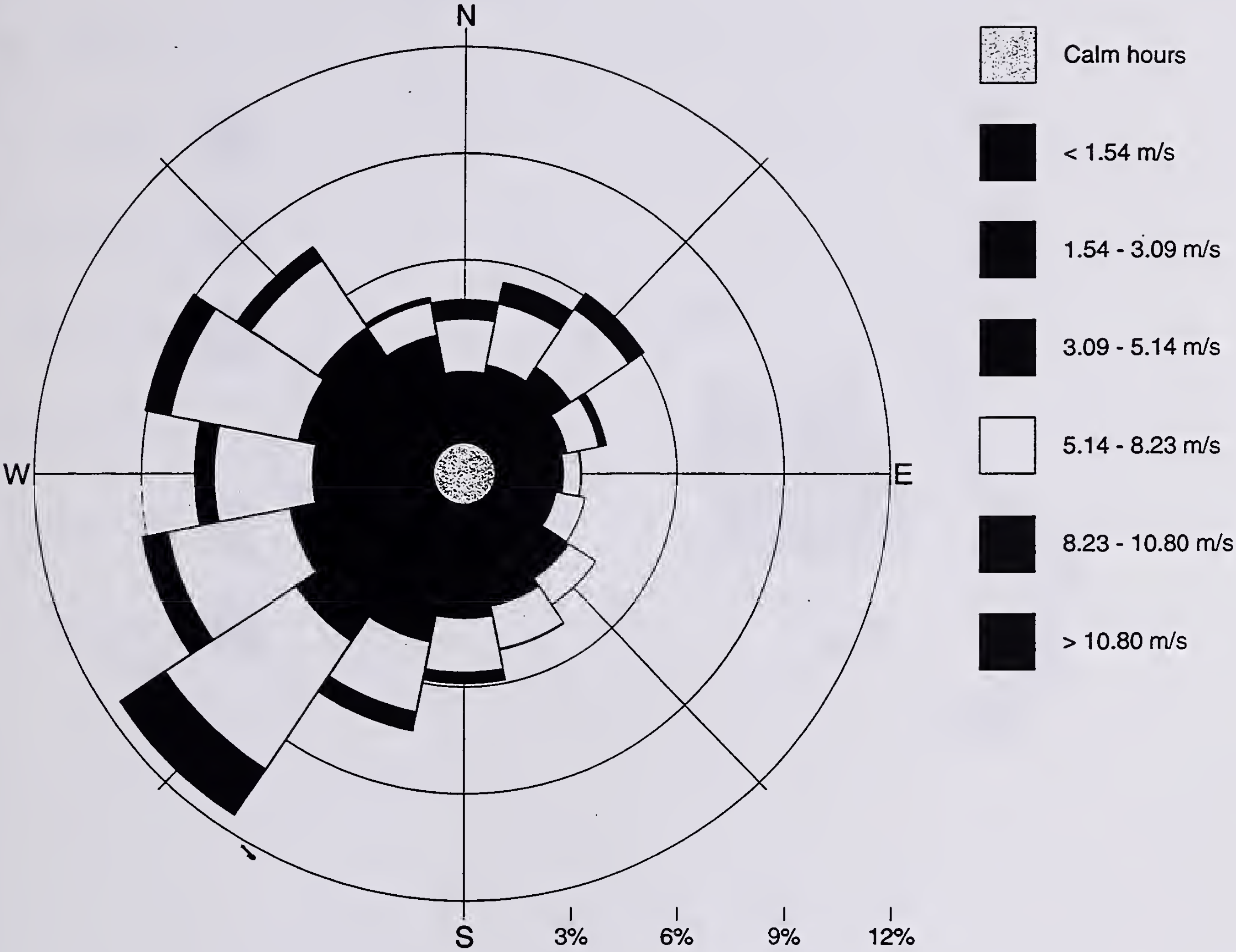


Year: 1988

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)

Windrose - mmrmet89.asc

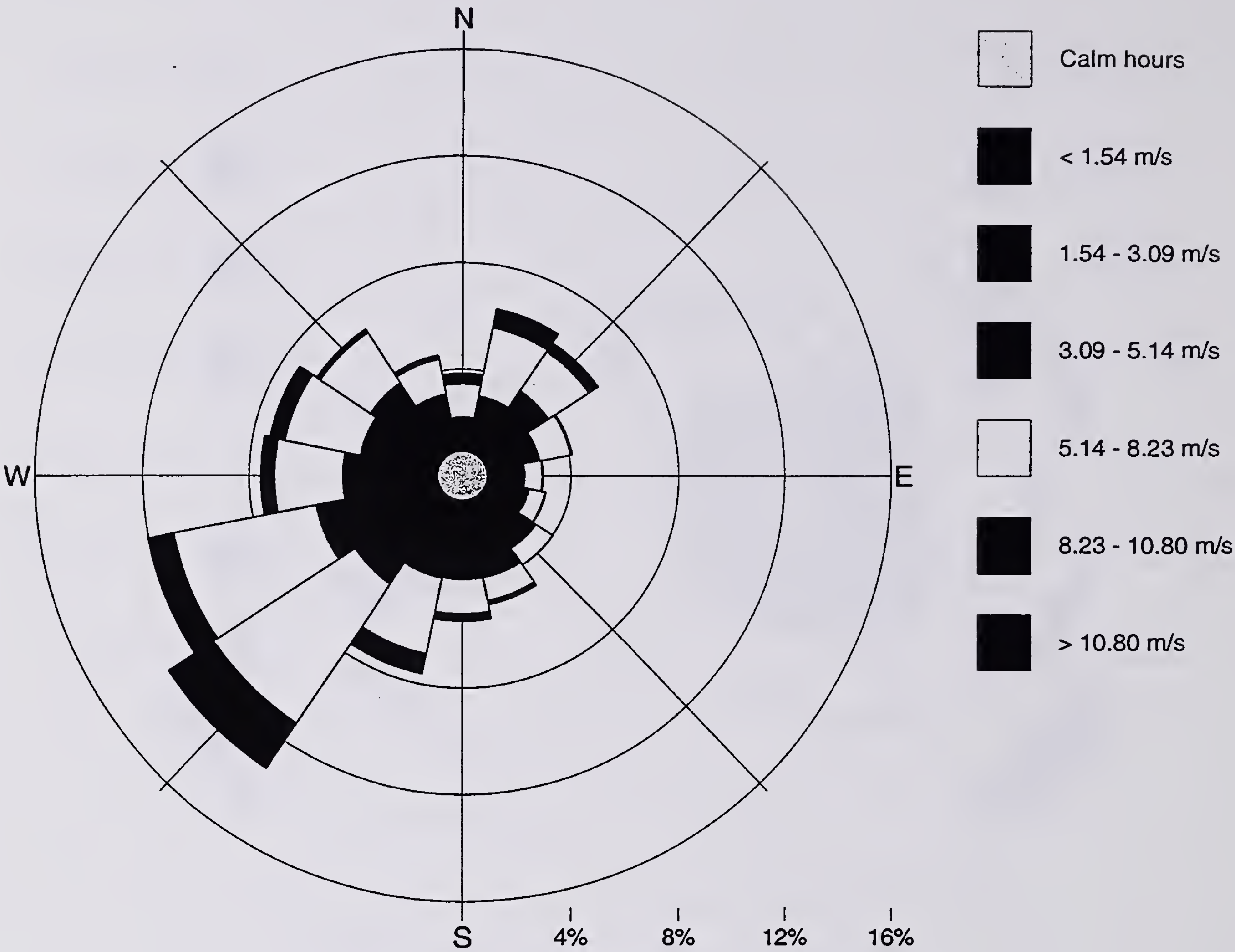


Year: 1989

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)

Windrose - mmrmet90.asc

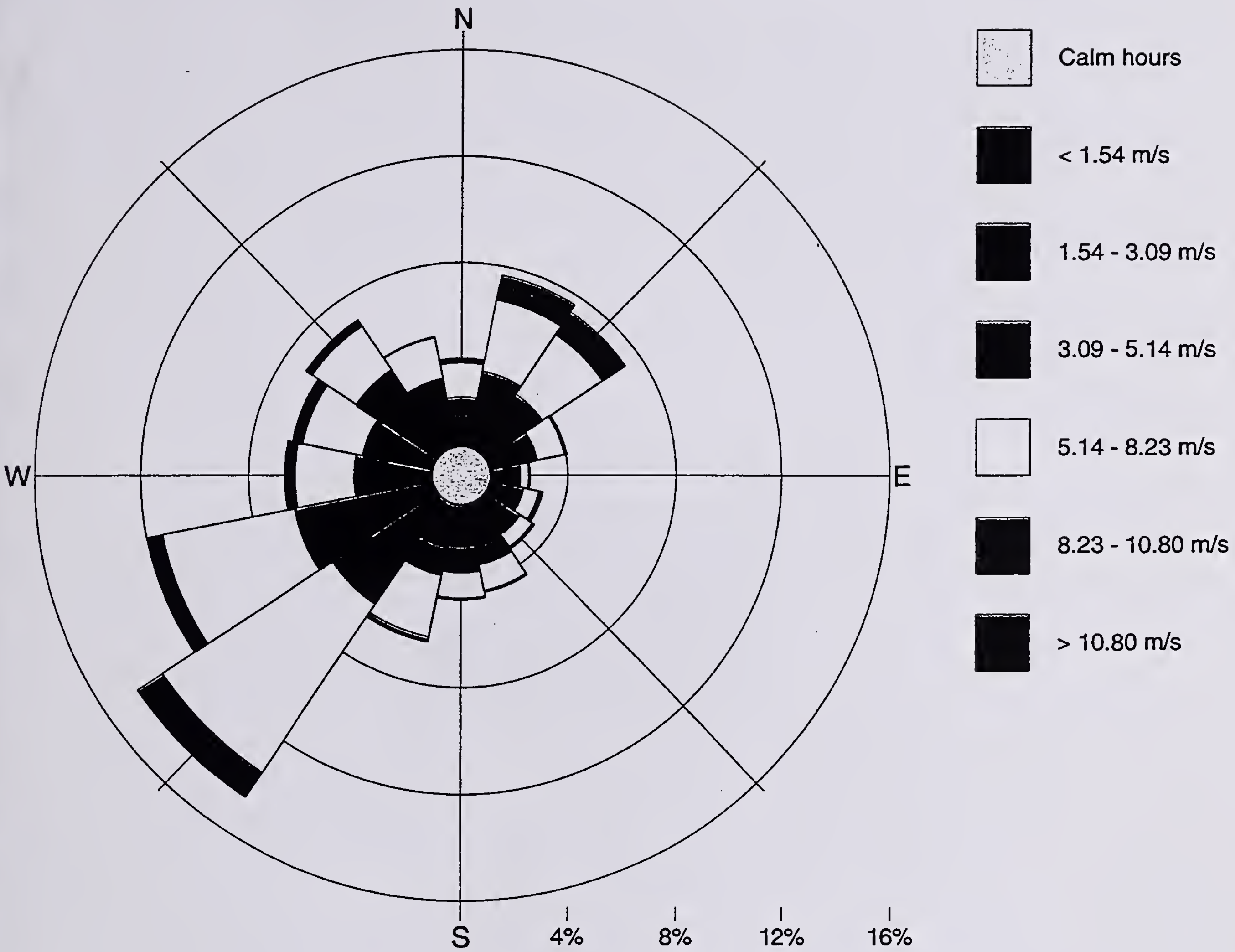


Year: 1990

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)

Windrose - mmrmet91.asc



Year: 1991

Surface Station No. 14704 (Otis Air National Guard, MA)

Upper Air Station No. 14684 (Chatham, MA)